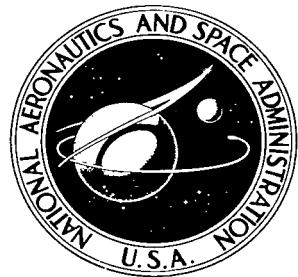


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A FORTRAN PROGRAM TO CALCULATE THE FLOW FIELD AND PERFORMANCE OF AN AXIALLY SYMMETRIC deLAVAL NOZZLE

by D. Thompson, E. H. Ingram,
C. T. K. Young, and J. B. Cox

George C. Marshall Space Flight Center
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	1
PROGRAM DESCRIPTION	3
Program Composition	3
Routine and Subroutine Functions	3
The Main or Control Routine	3
Subroutine CASE 1	7
Subroutine CASE 2	7
Subroutine CASE 3	8
Subroutine CASE 4	8
Subroutine THERMO	9
Subfunction PL TN	10
Subroutine STREAM	10
Subroutine OPTIMS	10
Subroutine POLY	11
Subroutine PROPTY	11
Subroutine PERFOR	12
The Plotter Program	12
Flow Charts of the Nozzle Program	13

TABLE OF CONTENTS (Concluded)

	Page
FORTRAN IV Listing of the Nozzle Program	52
PROGRAM UTILIZATION	107
Program Input Data	107
Program Output	113
Error Conditions	114
Mesh Size	114
Range of Thermodynamic Table	115
Starting Line	115
Shock Waves	115
Inaccurate Description of the Nozzle Contour . . .	116
Sample Problem - Evaluation of a "Perfect" Nozzle . .	116
Given Information	116
Program Results	117
APPENDIX A - The Characteristic Unit Processes	133
APPENDIX B - Equations for the Calculation of Hall's Constant Property Curve	143
APPENDIX C - Equations for the Calculation of Nozzle Performance	148
REFERENCES	150

LIST OF ILLUSTRATIONS

Figure	Title	Page
1	Flow Net of an Axially Symmetric deLaval Nozzle	4
2	Geometry of Throat	110
3	The Characteristic Net	118
4	Streamlines	119
A-1	Field Point Unit Process	134
A-2	Unit Process for Point on Axis of Symmetry	138
A-3	Unit Process for Point on a Solid Boundary	140

LIST OF SYMBOLS

<u>Mathematical</u>	<u>FORTRAN</u>	<u>Definition</u>
A	A	Cross-sectional area
A	FMATRIX	Polynomial coefficient
a	A	$f_a(\gamma)$, defined in Appendix B
b	B	$f_b(\gamma)$, defined in Appendix B
C_f	CF	Thrust coefficient
c	C	Speed of sound
$\frac{dg_0}{dy}$	DG0DY	Differential of g_0 with respect to y
$\frac{dg_1}{dy}$	DG1DY	Differential of g_1 with respect to y
$\frac{dg_2}{dy}$	DG2DY	Differential of g_2 with respect to y
$\frac{dy}{dx}$	DYDX	Differential of y with respect to x
$\frac{dz}{dy}$	DZDY	Differential of z with respect to y
g_0	G0	$f_6(Q, y)$, defined in Appendix B
g_1	G1	$f_7(g_0, y, \gamma)$, defined in Appendix B
g_2	G2	$f_8(g_0, y, \gamma)$, defined in Appendix B
M	FM	Mach number
M^*	FMS	Reference Mach number
\dot{m}	FLOW	Mass flow rate
P	P	Static pressure
\bar{R}		Universal gas constant

LIST OF SYMBOLS (Continued)

<u>Mathematical</u>	<u>FORTRAN</u>	<u>Definition</u>
Q	BQ	$f_5(M^*, R)$, defined in Appendix B
\bar{q}	QBAR	Reference Mach number on the initial value curve
q_1	Q1	$f_1(y, z)$, defined in Appendix B
q_2	Q2	$f_2(y, z)$, defined in Appendix B
q_3	Q3	$f_3(y, z)$, defined in Appendix B
R	R	Radius of curvature of the throat contour
R_t	RT	Throat radius
Sp. Imp.	SPIPLS	Specific impulse
T	T	Static temperature
v	V	Velocity
w	FMW	Molecular weight
x	X	x-coordinate, parallel to the axis of symmetry
y	Y	y-coordinate, normal to the axis of symmetry
z	Z	$z = f(x)$, defined in Appendix B

Greek Symbols

α	ALPHA	Mach angle
β	BETA	Characteristic coefficient
Γ	PULSE	Thrust
Γ	PUSH	Thrust

LIST OF SYMBOLS (Concluded)

<u>Mathematical</u>	<u>FORTRAN</u>	<u>Definition</u>
$\bar{\gamma}$	GBAR	Average ratio of specific heat
γ	G	Ratio of specific heats
H	H	Characteristic coefficient
θ	THETA	Velocity inclination angle
θ_1	THETA 1	$f_9(y, z)$, defined in Appendix B
θ_2	THETA 2	$f_{10}(\gamma, y, z)$, defined in Appendix B
θ_3	THETA 3	$f_{11}(\gamma, y, z)$, defined in Appendix B
λ	FLAM	Characteristic coefficient
ρ	RHO	Mass density
 <u>Subscripts</u>		
a	A	Ambient condition
c	C	Denotes chamber condition
e	EXIT	Denotes condition at the nozzle exit
l	L	Denotes a point on a left-running characteristic
l, n	LN	Average value of variable between points l and n
n	N	Denotes a lattice point
r	R	Denotes a point on a right-running characteristic
r, n	RN	Average value of variable between points r and n
s	S	Denotes a point on the starting line
w	WALL	Denotes a point on the nozzle contour

A FORTRAN PROGRAM TO CALCULATE
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AN AXIALLY SYMMETRIC deLAVAL NOZZLE

By

D. Thompson, E. H. Ingram*, C. T. K. Young*, and J. B. Cox*

SUMMARY

A FORTRAN IV computer program was developed for calculation of the flow pattern and performance of axially symmetric deLaval nozzles, using the axially symmetric method of characteristics for isentropic flow. The program computes thermodynamic and gasdynamic properties throughout the flow field and performance parameters (e.g. thrust, specific impulse, etc.) at various stations. The capabilities, limitations, optional features, physical structure and use of this program are described in detail.

INTRODUCTION

An IBM 7040 FORTRAN IV computer program was developed to analyze axially symmetric deLaval nozzles. The nozzle program utilizes the axially symmetric method of characteristics for isentropic flow.

The program computes thermodynamic and gasdynamic properties throughout the flow field and performance parameters (e.g. thrust, specific impulse, etc.) at various stations. The computer program utilizes the General Dynamics/Electronics SC-4020 plotter to produce pictorial plots of the characteristic net and streamlines.

The chemical composition of the gas is assumed to be either "frozen" or in chemical equilibrium. Furthermore, for "frozen"

*Research Laboratories, Brown Engineering Company, Inc.

composition, the specific heats of the gas may either be functions of temperature or constants (perfect gas).

This report describes the capabilities, limitations, optional features, physical structure and use of this computer program. The report is divided into two parts: PROGRAM DESCRIPTION and PROGRAM UTILIZATION. Program composition, functions of the program components, flow charts, and FORTRAN listings are contained in the first part. The second part of the report discusses input, output, and error conditions; the flow field and performance of a perfect nozzle are computed as an example problem.

The characteristic equations*, performance relations, transonic flow equations and other relations coded in the nozzle program are given in the appendices.

The technical effort in formulating this report was performed by personnel of the Research Laboratories, Brown Engineering Company, Inc., under Contract NAS8-5289.** Technical management of the project was provided by Donald D. Thompson, Advanced Propulsion Section, Engine Systems Branch, Propulsion Division, Propulsion and Vehicle Engineering Laboratory, George C. Marshall Space Flight Center.

*See Reference 1 for a detailed development of the characteristic unit processes and other numerical procedures which are utilized in this computer program.

**Reference Brown Engineering Company, Inc. Technical Note R-82.

PROGRAM DESCRIPTION

Program Composition

The nozzle analysis program is composed of a main or control routine and subroutines to compute the characteristic net, basic thermodynamic and gasdynamic functions, streamlines, an initial value curve, and performance parameters. In addition, the program contains two non-library mathematical subroutines, an interpolation subfunction and a curve-fitting subroutine.

Routine and Subroutine Functions

The Main or Control Routine. The main routine is the controlling element of the program. The basic functions of the main routine are to supply input data to the various subroutines, direct the entry to the subroutines in a logical pattern, and process the output from the subroutines.

The procedure by which the main routine performs these functions can be explained by following the construction of the flow net which is illustrated in FIG 1. The main routine first reads all necessary information (see Input) into core. Depending on the input data, some initial calculations may be made; e. g., if points on the starting line have not been read in, the main routine will utilize the initial value curve subroutine to compute these points. The input data is now printed "on line". The main routine then proceeds to direct the construction of the flow net.

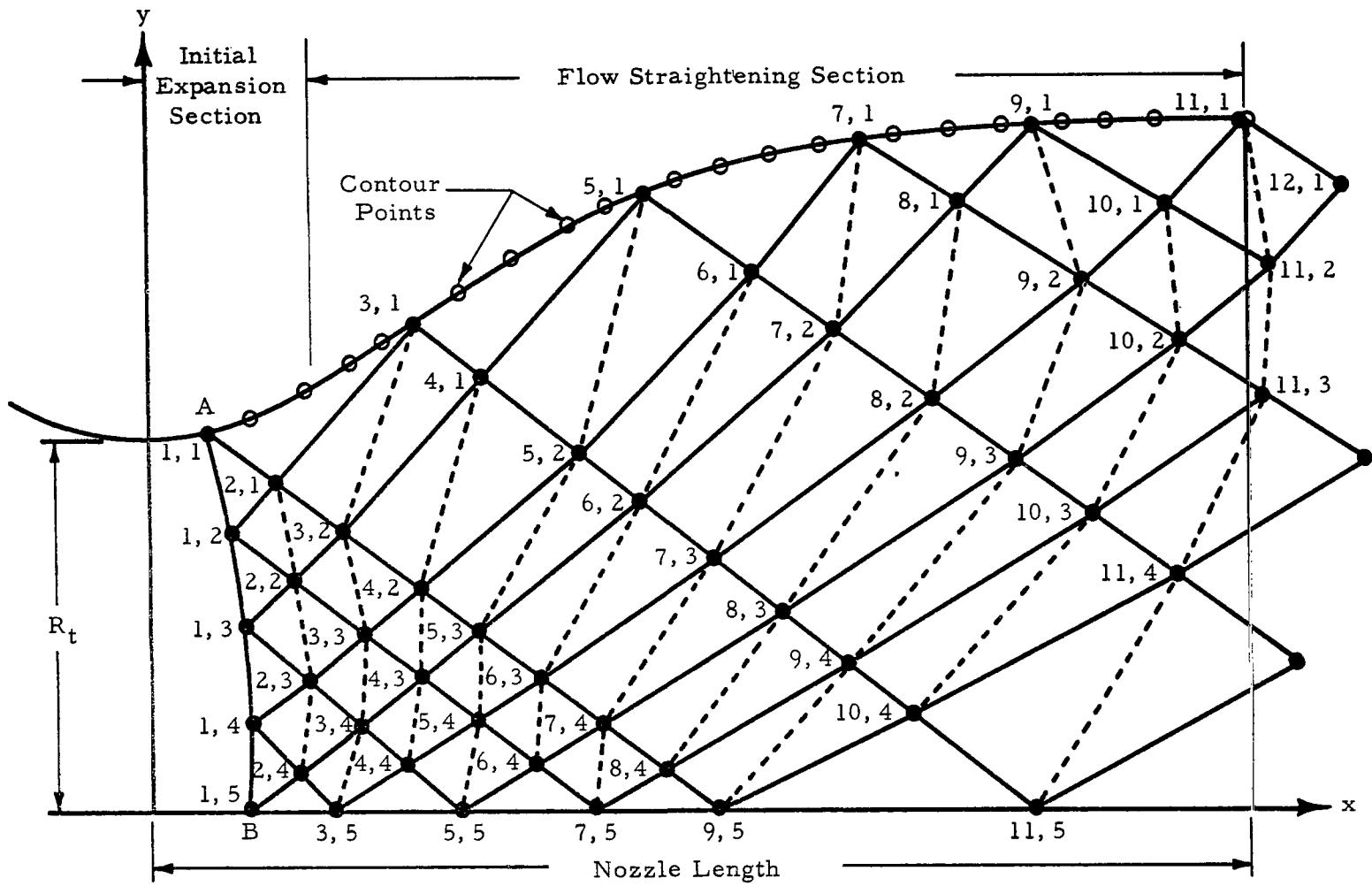


Figure 1 - Flow Net of an Axially Symmetric Laval Nozzle

Each lattice point* is represented by two subscripts, I and J, where I is the row, shown by the dashed lines in FIG 1, and J designates a certain point on the Ith row. Note that the matrix representation is used only for control and identification purposes; due to the limitation of storage capacity, 32K, all lattice points are not stored. At any time, no more than two consecutive rows of points (represented by x, y, θ, and M*) appear in storage with the exception of points on the starting line and calculated contour points which are required for the calculation of nozzle performance.

Beginning with the known points on the initial value curve, AB in FIG 1, the lattice points are calculated row wise. Specifically, the lattice points (2, 1), (2, 2), and (2, 3) are calculated by the characteristic subroutine CASE 1 using the known combinations, (1, 1 and 1, 2), (1, 2 and 1, 3), and (1, 3 and 1, 4) respectively. Using points (1, 4 and 1, 5) as input, the characteristic subroutine CASE 2 is used to determine the point (2, 4). After the completion of each row, the streamlines from points on the initial value curve are extended from the previous row to the new row. Thus, at this point, the streamline segments between row 1 and row 2 are computed by subroutine STREAM. The points on row 2 are now used to compute the points on row 3. Using the known point (2, 1), the boundary

* A lattice point is the point at which two different-family characteristics intersect.

point, (3, 1) is computed by the characteristic subroutine CASE 4. The lattice points (3, 2), (3, 3), and (3, 4) are next computed by subroutine CASE 1 using the combinations (2, 1 and 2, 2), (2, 2 and 2, 3), and (2, 3 and 2, 4) respectively. The point on the axis of symmetry, (3, 5), is now computed by subroutine CASE 3 using the known point (2, 4). The stream-line segments from row 2 to row 3 are computed.

The odd rows, i. e. when I is odd, contain the same number of lattice points and the same type points, i. e. one boundary point, one point on the axis of symmetry, and N-2 field points, as the initial value curve. Therefore, row 3 may be thought of as being an initial value curve and the calculation procedure described in the previous paragraph is repeated to obtain successive rows.

Normally, the construction of the flow net is terminated when a contour point is found beyond the specified nozzle length. However, there are two exceptions to this termination. A characteristic cut-off point on the axis of symmetry may be specified as input to the program. In this case, the flow net will not be computed downstream of the left running characteristic which originates at the cut-off point. The second exception to the normal termination of the flow net occurs when an error condition is encountered. For example, one of the characteristic subroutines may return a bad solution due to the formation of a shock wave in the flow field. In this case, points downstream of the shock wave will not be computed.

When the flow net has been completed, the thrust, thrust coefficient, and specific impulse are calculated at various stations along the nozzle

contour and also at the nozzle exit (provided of course that no error conditions were encountered during the construction of the flow net).

During the construction of the flow net, coordinates of the lattice points are written on FORTRAN tape 2 and the coordinates of the streamlines are written on FORTRAN tape 1. At the end of each nozzle case, the information on tape 1 is transferred to tape 2 so that multiple nozzle cases may be processed. Tape 2 is then used as an input tape for the plotter program*.

Subroutine CASE 1. Subroutine CASE 1 uses two known lattice points to compute a third lattice point by the method of characteristics. The two input points are general field points. However, an input point can not be located on the axis of symmetry. The flow angle is tested and improved by successive iterations until an accuracy of 10^{-7} is obtained or 50 iterations, whichever comes first. The characteristic equations for CASE 1 are given in Appendix A.

Subroutine CASE 2. Subroutine CASE 2 is almost identical to subroutine CASE 1. The difference being that in subroutine CASE 2 one of the known lattice points is located on the nozzle axis and the other point is located in the field. The same iteration procedure as used in CASE 1 is used in CASE 2. The characteristic equations for CASE 2 are given in Appendix A.

* The plotter program is an auxiliary program which utilizes the General Dynamics/Electronics SC-4020 plotter to produce pictorial plots of the flow net.

Subroutine CASE 3. Subroutine CASE 3 requires only one input point which is located near the axis of symmetry. This subroutine computes the gasdynamic properties at the intersection of the right-running characteristic from the known point with the nozzle axis. The reference Mach number, M^* , is improved by successive iterations until a convergence of 10^{-7} is obtained or 50 iterations, whichever comes first. The characteristic equations for CASE 3 are given in Appendix A.

Subroutine CASE 4. Subroutine CASE 4 calculates the gasdynamic properties at a point on the nozzle contour. This point is physically located at the intersection of the left-running characteristic from a known point (adjacent to the boundary) with the nozzle contour. Furthermore, the velocity vector must be tangent to the nozzle contour at the intersection point (assuming no flow separation). Therefore, it is essential that the nozzle contour be described accurately (see Error Conditions).

The initial expansion contour, i. e. the throat section, is frequently composed of sections of circular arcs (with different radii of curvature). The flow-straightening section is almost always described by numerical data. Therefore, the program assumes the initial expansion contour to be composed of up to five sections of circular arcs, two being located upstream of the throat and the other three downstream of it. The flow-straightening section is assumed to be described by numerical data. However, if the lengths of the circular sections downstream of the throat are given the values of zero, CASE 4 assumes the entire contour is described by numerical data.

If the left-running characteristic from the known field point crosses the nozzle contour in a region described by circular sections, the exact equations are used to determine the intersection point and corresponding contour slope. Curve-fitting techniques are used to determine the intersection point and corresponding slope when the left-running characteristic crosses a boundary which is described numerically. The segment of the contour which is described by $N + 1$ numerical points is curve-fitted by an N^{th} degree polynomial. The $N + 1$ points are chosen so that points are located on both sides of the intersection point.

After the intersection point and corresponding boundary slope have been determined, the left-running characteristic equation is solved for the reference Mach number on the boundary. The reference Mach number and other flow variables are improved by successive iterations until the reference Mach number converges to 10^{-7} or 50 iterations, whichever comes first.

The characteristic equations for CASE 4 are given in Appendix A.

Subroutine THERMO. Subroutine THERMO computes the thermodynamic table for isentropic flow. The chamber pressure, chamber temperature, molecular weight (constant), and ratio of specific heats (constant) are the necessary input values.

The subroutine computes up to 80 data points, each data point consisting of a pressure, temperature, molecular weight, specific heats ratio, Mach number, and reference Mach number. The table is computed

by incrementing the Mach number. In addition, this subroutine computes the critical sonic velocity.

This subroutine is used only for the case of "frozen" composition and constant specific heats. For other cases, the thermodynamic table is specified as input data.

Subfunction PLTN. Subfunction PLTN performs interpolation between any two columns in the thermodynamic table. If the value of the independent variable does not lie within the table limits, an error message will be executed and the subroutine proceeds to perform extrapolation.

Subroutine STREAM. Subroutine STREAM computes and writes on tape the coordinates of the streamline segments between consecutive lattice-point rows. The coordinates of the streamlines do not appear as printed output from the program but instead are used to construct a pictorial plot of the streamlines by utilizing the General Dynamics/Electronics SC-4020 microfilm plotter.

Subroutine OPTIMS. Subroutine OPTIMS applies Hall's theory (Reference 2) to compute an initial value curve. A specified number of input points (equally spaced along the y-axis) are computed along a constant property line. The particular constant property curve is determined by requiring that the right-running characteristic at the boundary extend downstream of the constant property curve.

The equations to calculate the starting line are given in Appendix B.

Subroutine POLY. Subroutine POLY calculates the coefficients of an N^{th} degree polynomial, $1 \leq N \leq 7$, for $N + 1$ consecutive numerical contour points.

The approximate location of a characteristic point on the nozzle contour is known to lie between the I^{th} and $(I + 1)^{\text{th}}$ contour points. The $N + 1$ contour points are selected in such a way that, if a vertical line was drawn between the I^{th} and $(I + 1)^{\text{th}}$ points, equal number of points will be located on each side of the line if N is odd and one more on the left side if N is even. Obviously, this procedure must be modified if the intersection point is located near the throat or near the nozzle exit.

The $(N + 1)$ simultaneous equations are solved by Jordan's elimination method. This method requires that none of the coefficients on the principal diagonal can be zero. Therefore, before the application of this method, subroutine POLY tests the coefficients on the principal diagonal; if a zero coefficient is found, the corresponding equation will be interchanged with the last equation.

Coefficients of the polynomial are stored in matrix form, $\text{FMTRIX}(1, N + 2) \dots \text{FMTRIX}(N + 1, N + 2)$, in descending order of the independent variable (e.g., $Y = AX^2 + BX + C$; then, $A = \text{FMTRIX}(1, 4)$, $B = \text{FMTRIX}(2, 4)$, and $C = \text{FMTRIX}(3, 4)$).

Subroutine PROPTY. For a known reference Mach number, subroutine PROPTY computes the corresponding Mach number, pressure, temperature, velocity and density. The thermodynamic table and subroutine PLTN are used.

Subroutine PERFOR. This subroutine calculates basic performance parameters of the nozzle. Initially, the mass flow rate is determined by integrating along the initial value curve. The thrust of the nozzle is calculated in two parts, the contribution of the momentum force at the throat and the contribution of the net pressure forces acting on the nozzle contour. As a result, the thrust and corresponding values of the thrust coefficient and specific impulse are calculated at various stations along the nozzle contour.

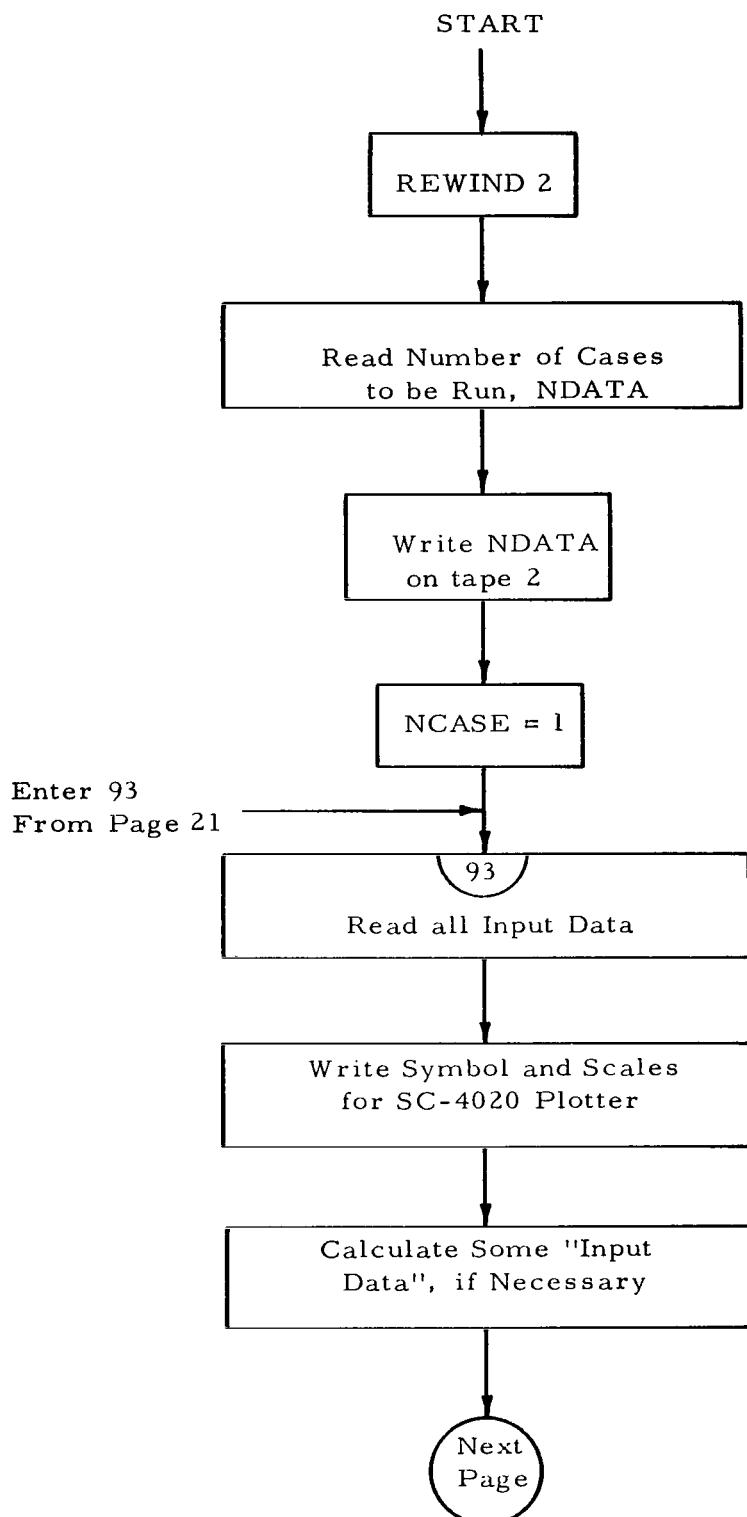
The equations used to calculate the nozzle performance parameters are given in Appendix C.

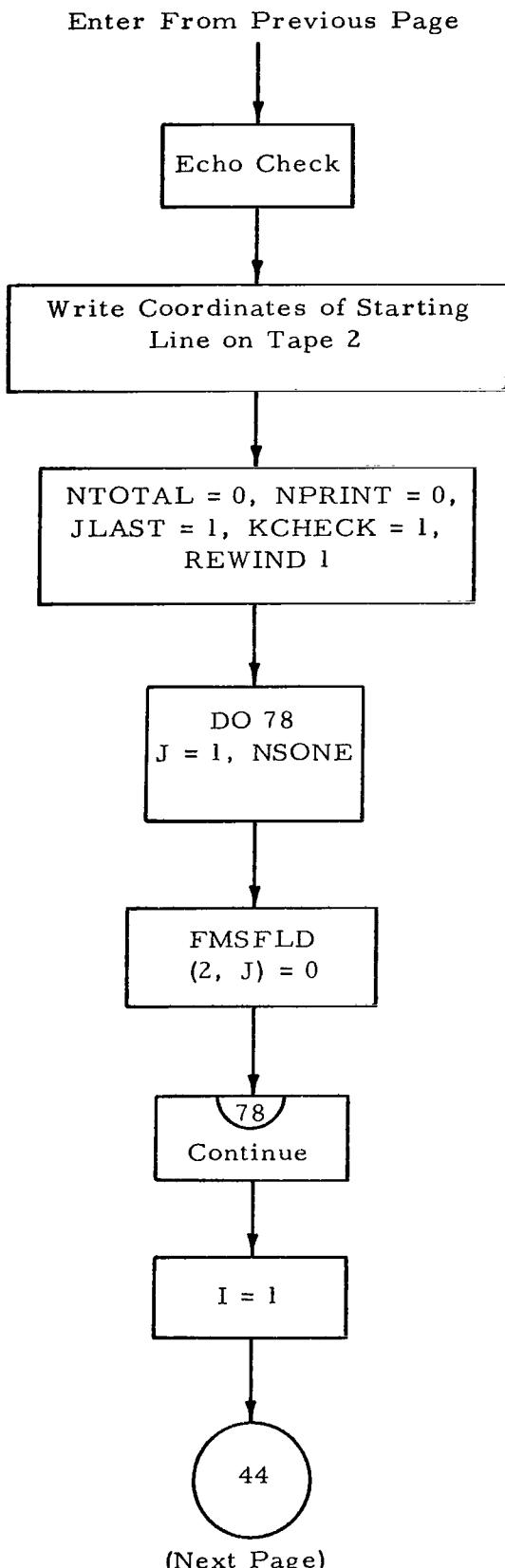
The Plotter Program

The plotter program is a separate auxiliary computer program which utilizes the General Dynamics/Electronics SC-4020 plotter to produce microfilm plots of the characteristic net and streamlines. The nozzle program constructs FORTRAN Tape 2 as the input for this program.

The plotter program uses basic plotter subroutines which were developed by North American Aviation, Inc. for line plots. Detailed descriptions of these subroutines are not given in this report.

MAIN PROGRAM





(Next Page)

Enter 44 From Page 14 or 19

44
JEND = NSONE - 1

Enter 45 From
Page 21

45
DO 20
J = 1, JEND

FMSFLD
(1, J) > 0

No 1002
(This Page)

Define X_R ,
 Y_R , M^*_R , M_R ,
 θ_R , X_L , Y_L ,
 M^*_L , M_L , θ_L

No

FMSFLD
(1, J+1) > 0

Yes

Call Subroutine
CASE 2

No

Y_L > 0

No

X_L > XNLTH

Yes

Call Subroutine
CASE 1

Yes

No

Yes

J > 1

1002

(This Page)

=1

KTEST

=0

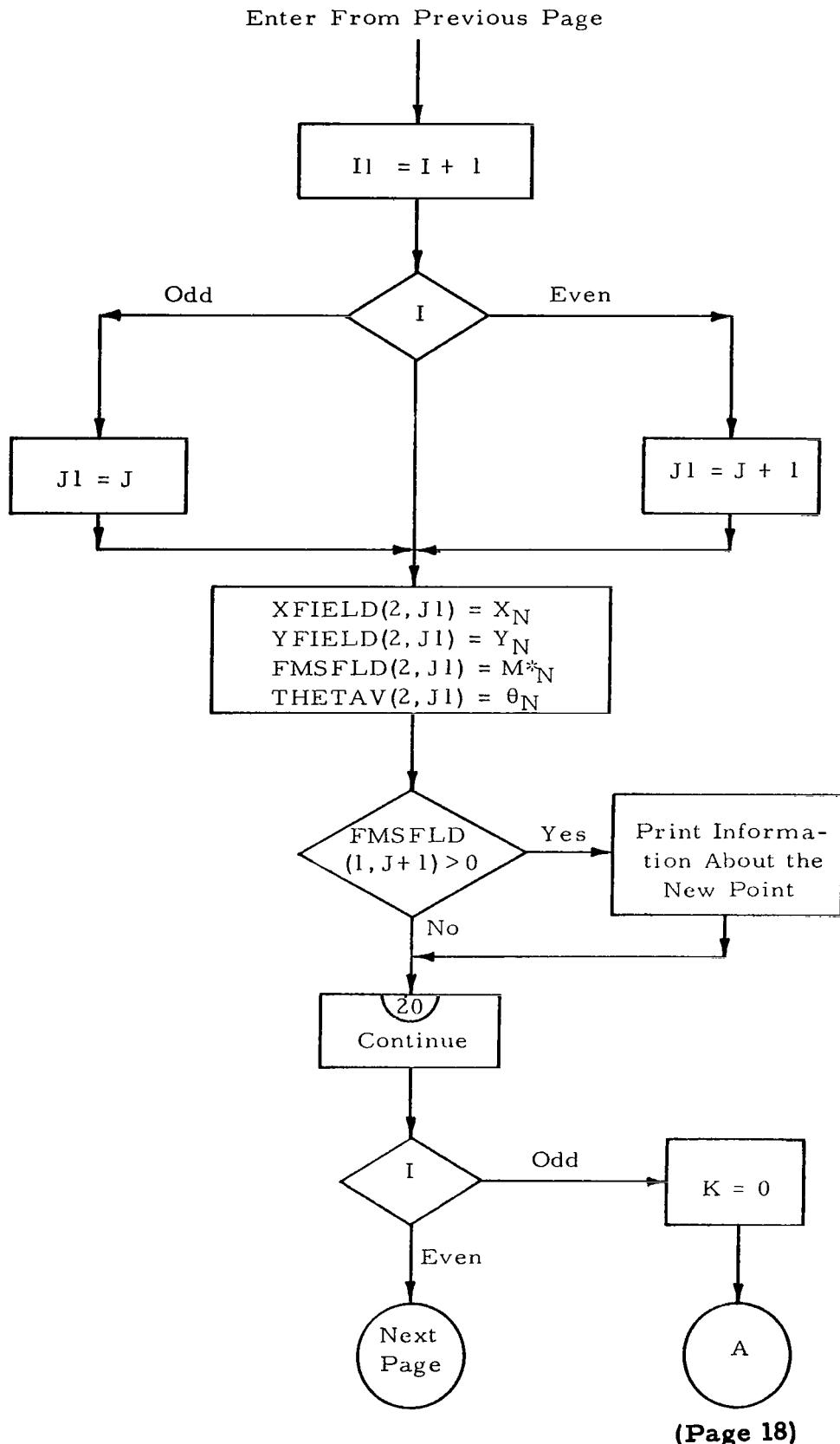
1002
 $M_N = 0$, $M^*_N = 0$,
 $P_N = 0$, $T_N = 0$
 $V_N = 0$, $\rho_N = 0$

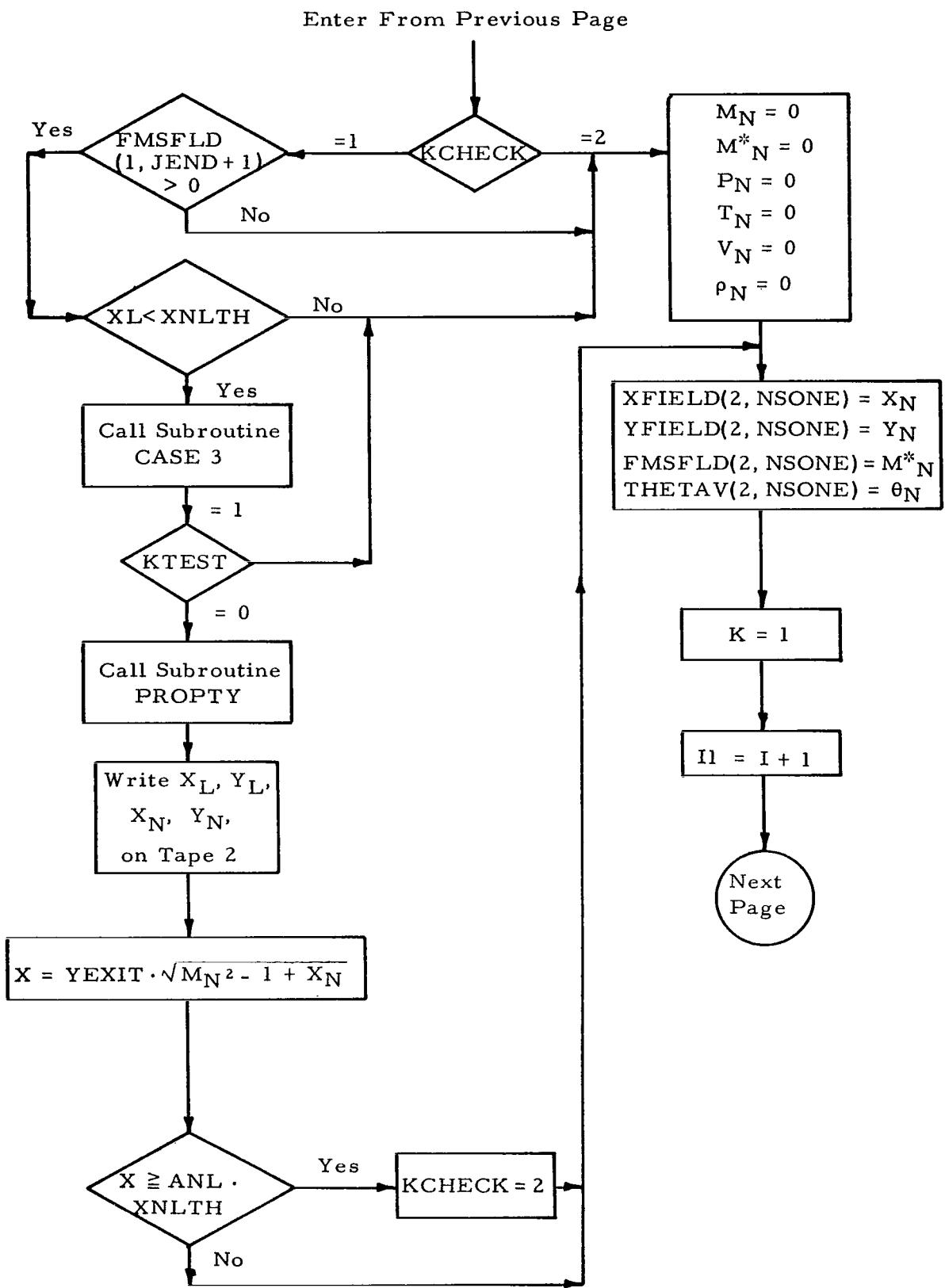
Call Subroutine
PROPTY

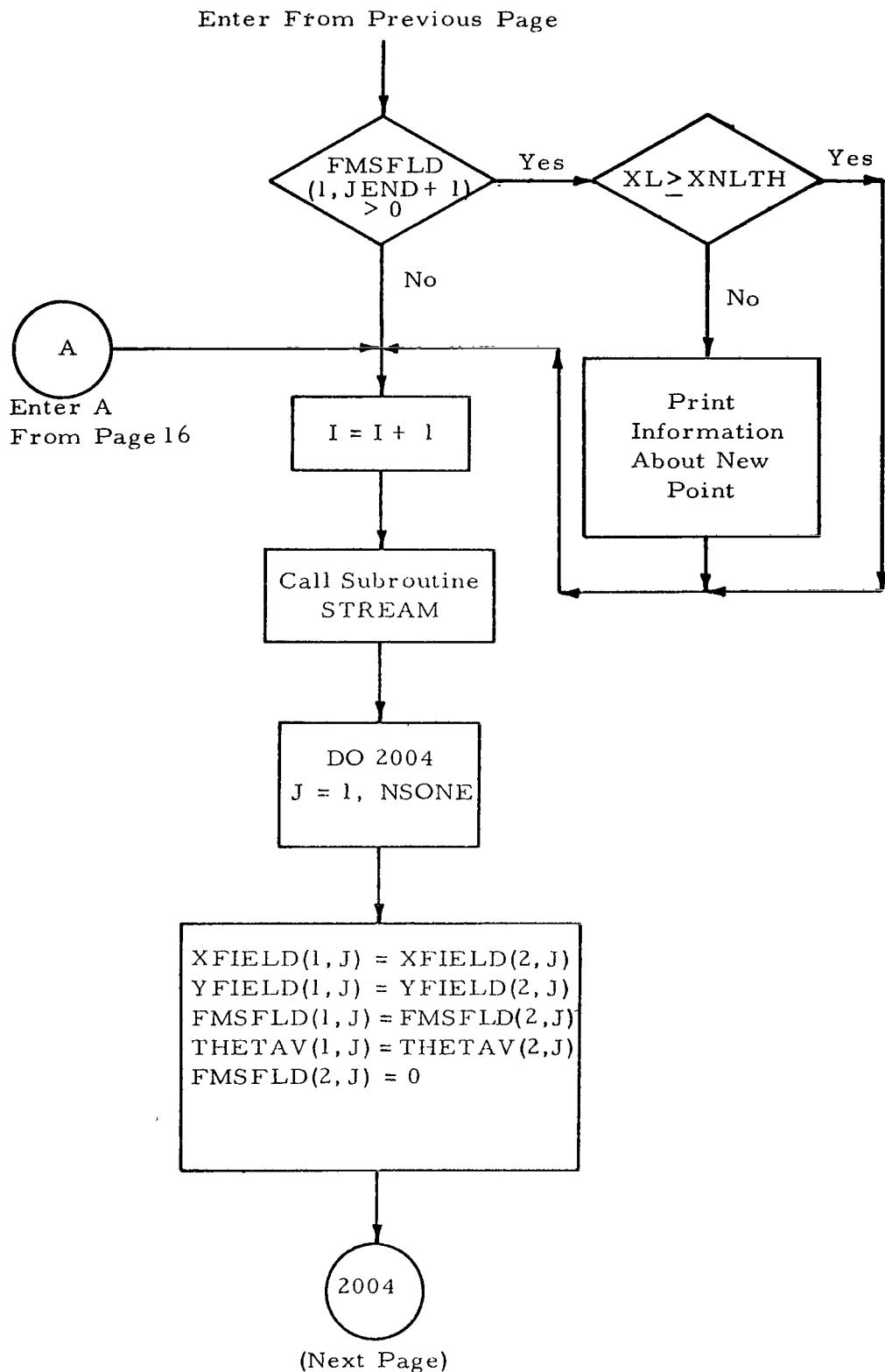
Write X_R , Y_R , X_N , Y_N
Write X_L , Y_L , X_N , Y_N
on Tape 2

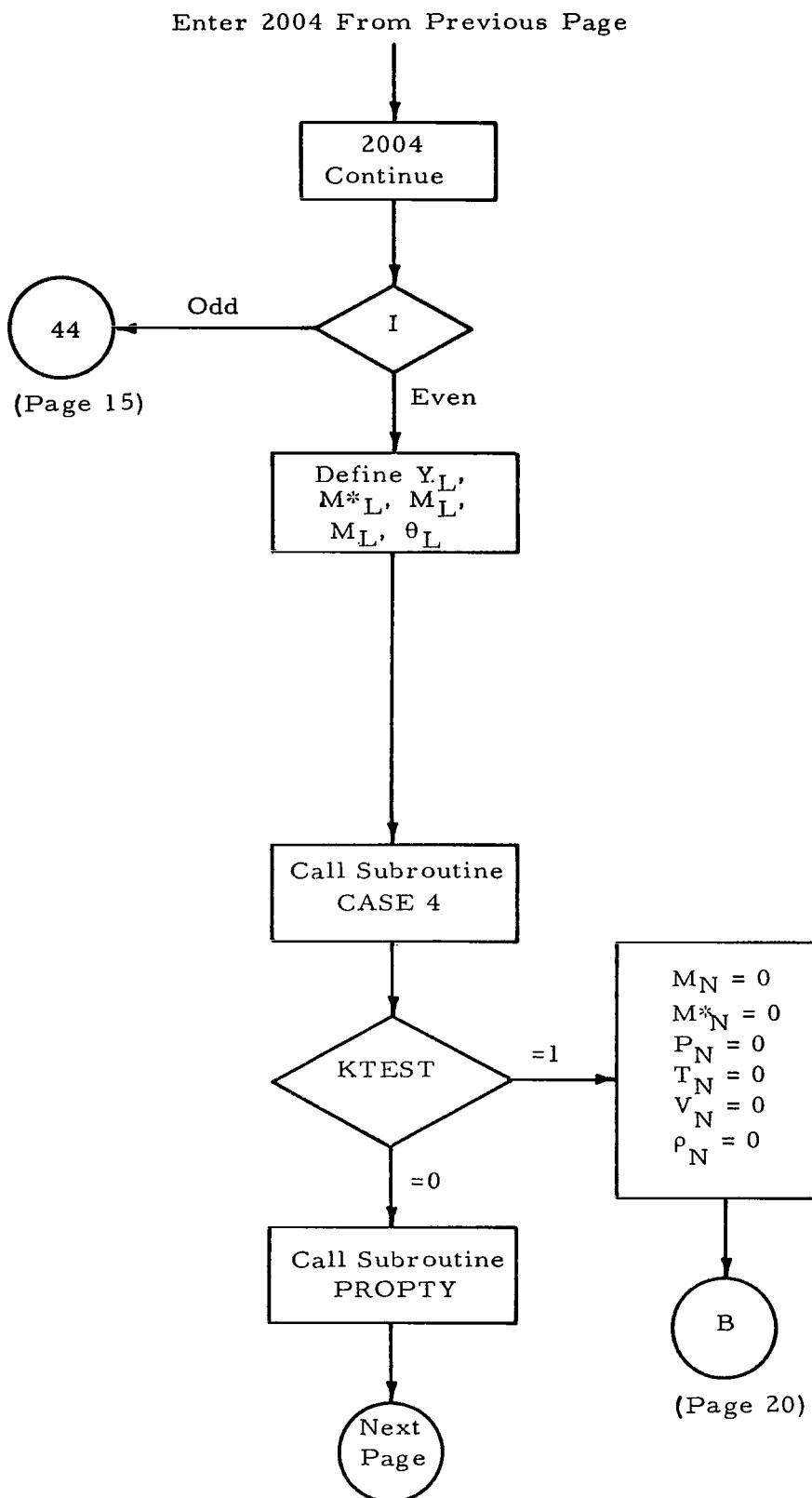
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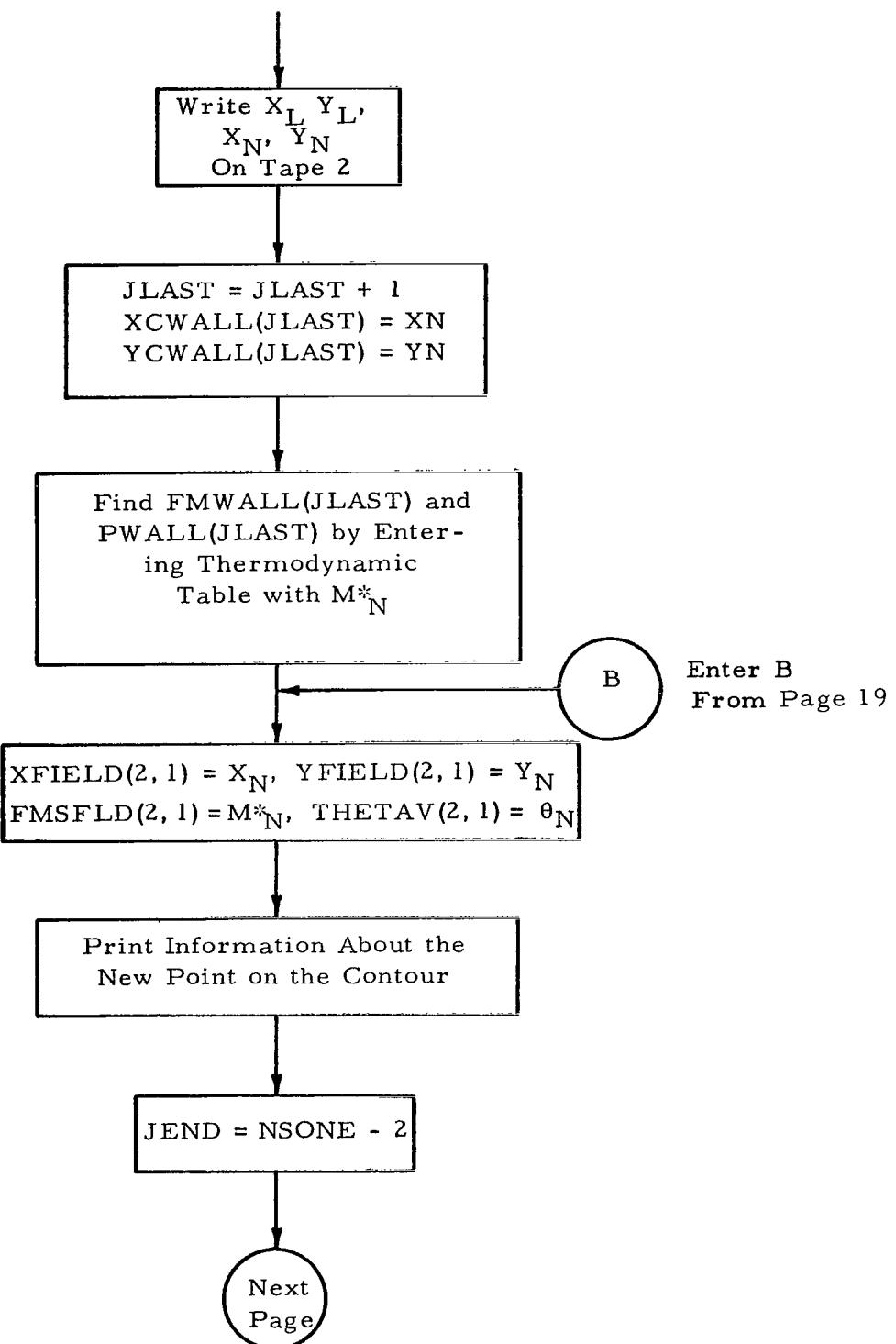


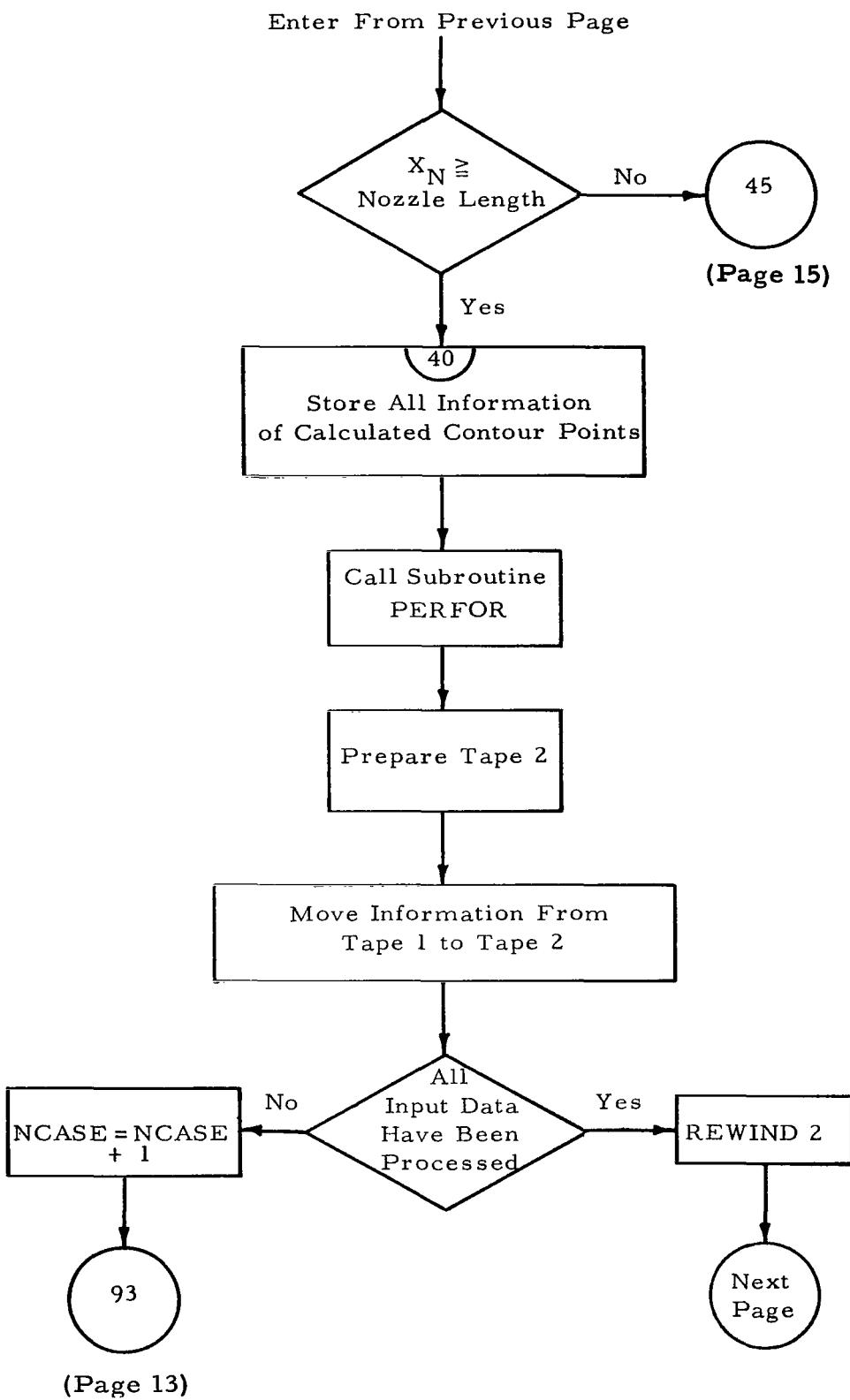






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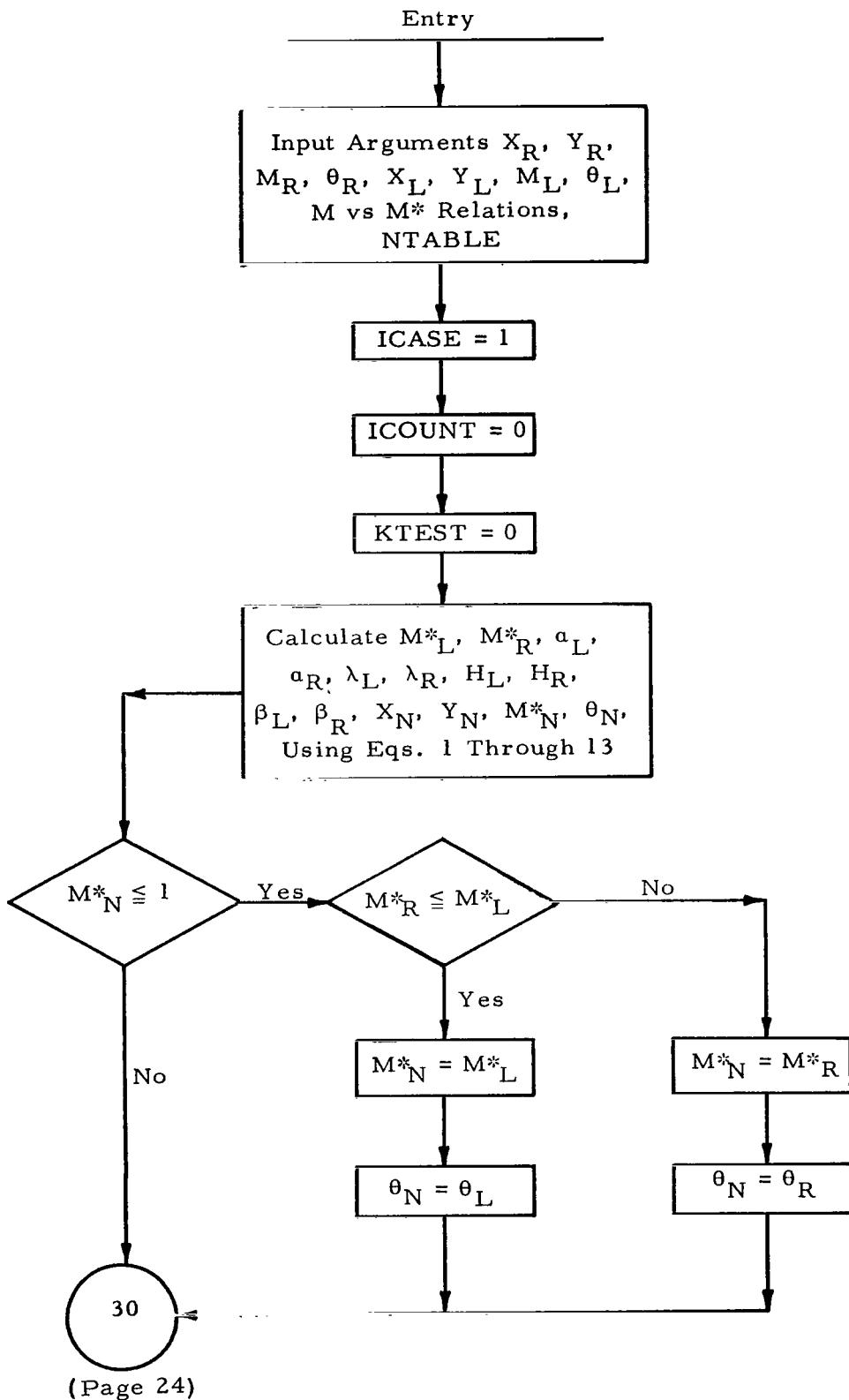
Pause 77777

**Unload and Save Tape 2
for SC-4020 Plotter**

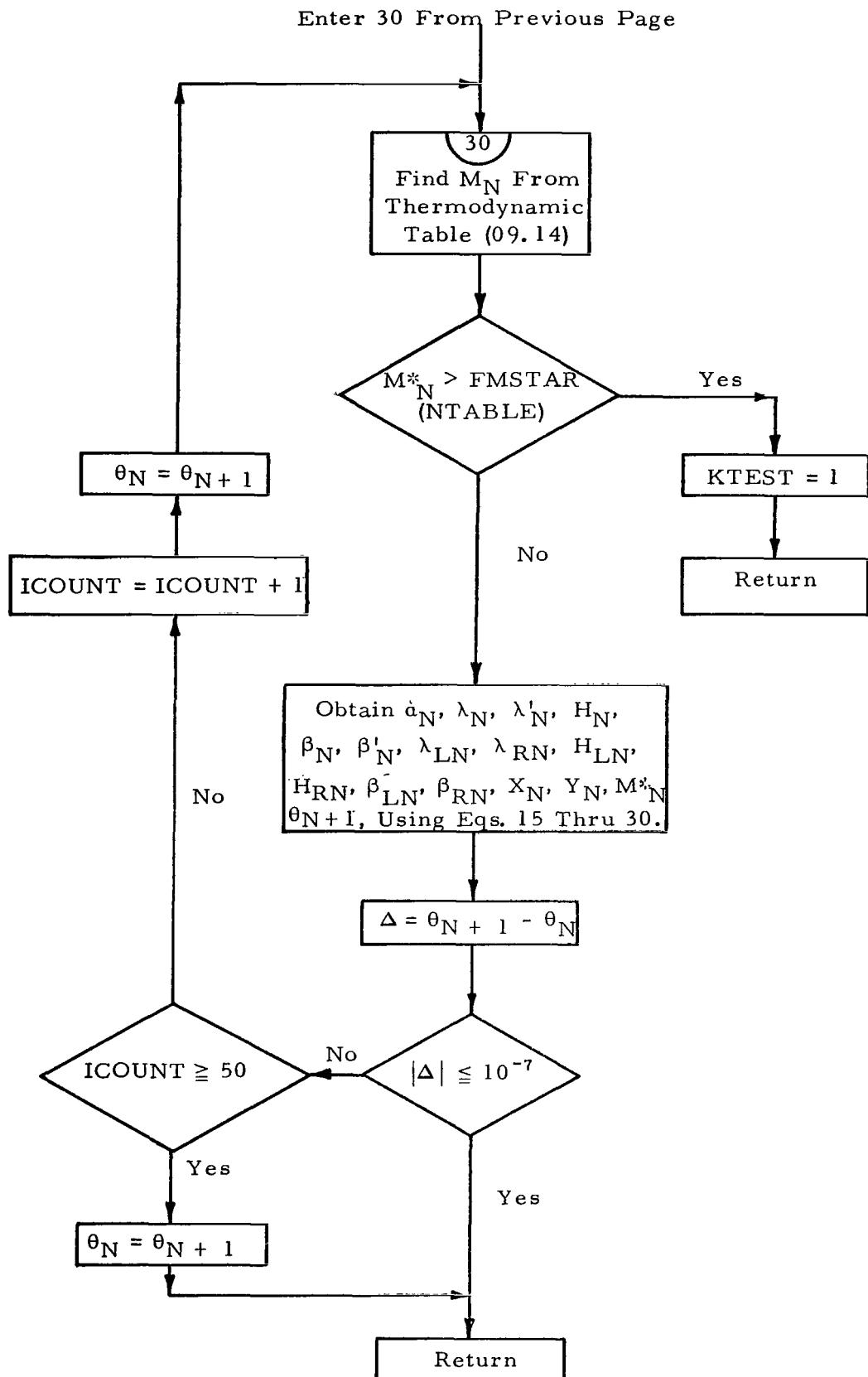
Call EXIT

End

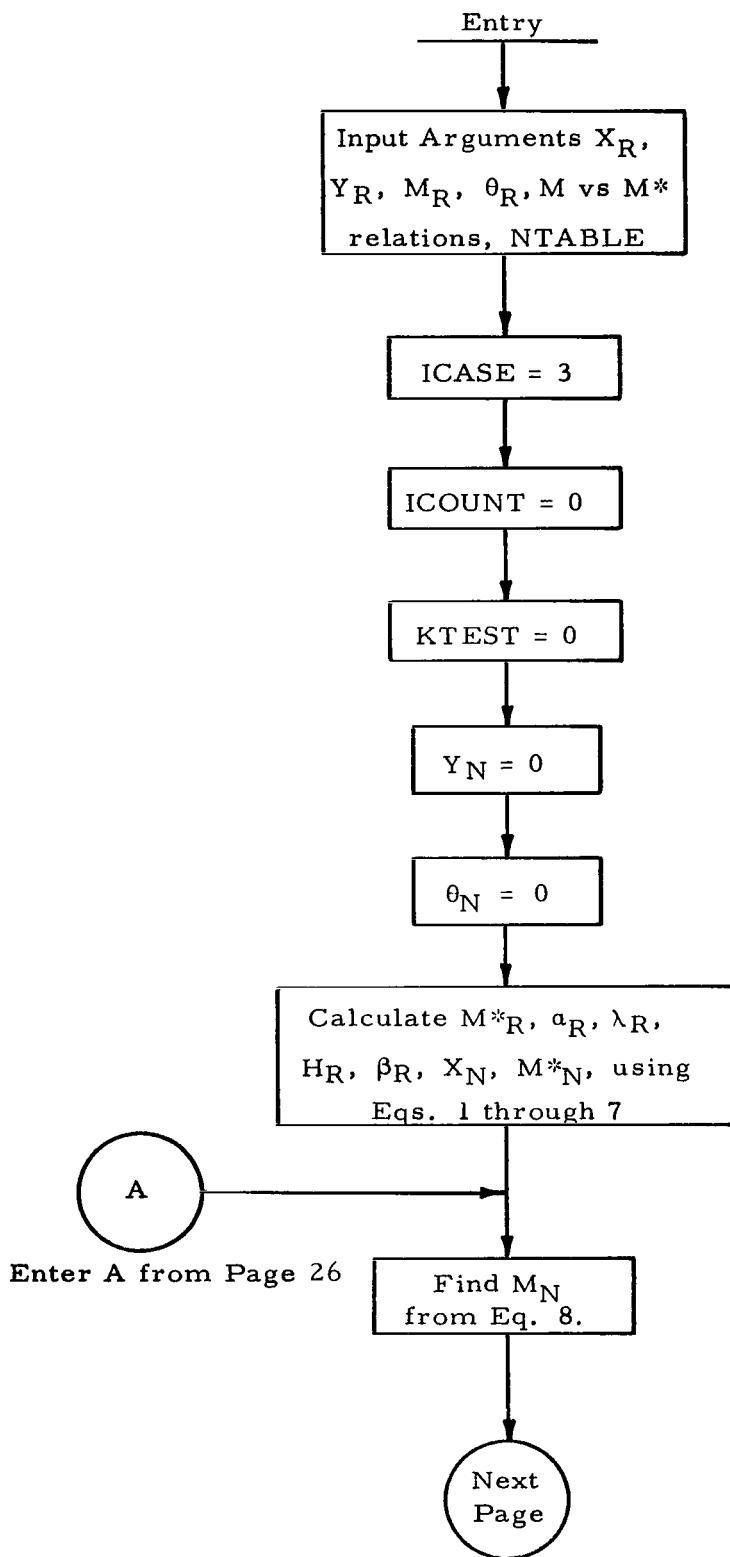
SUBROUTINE CASE1



(Page 24)

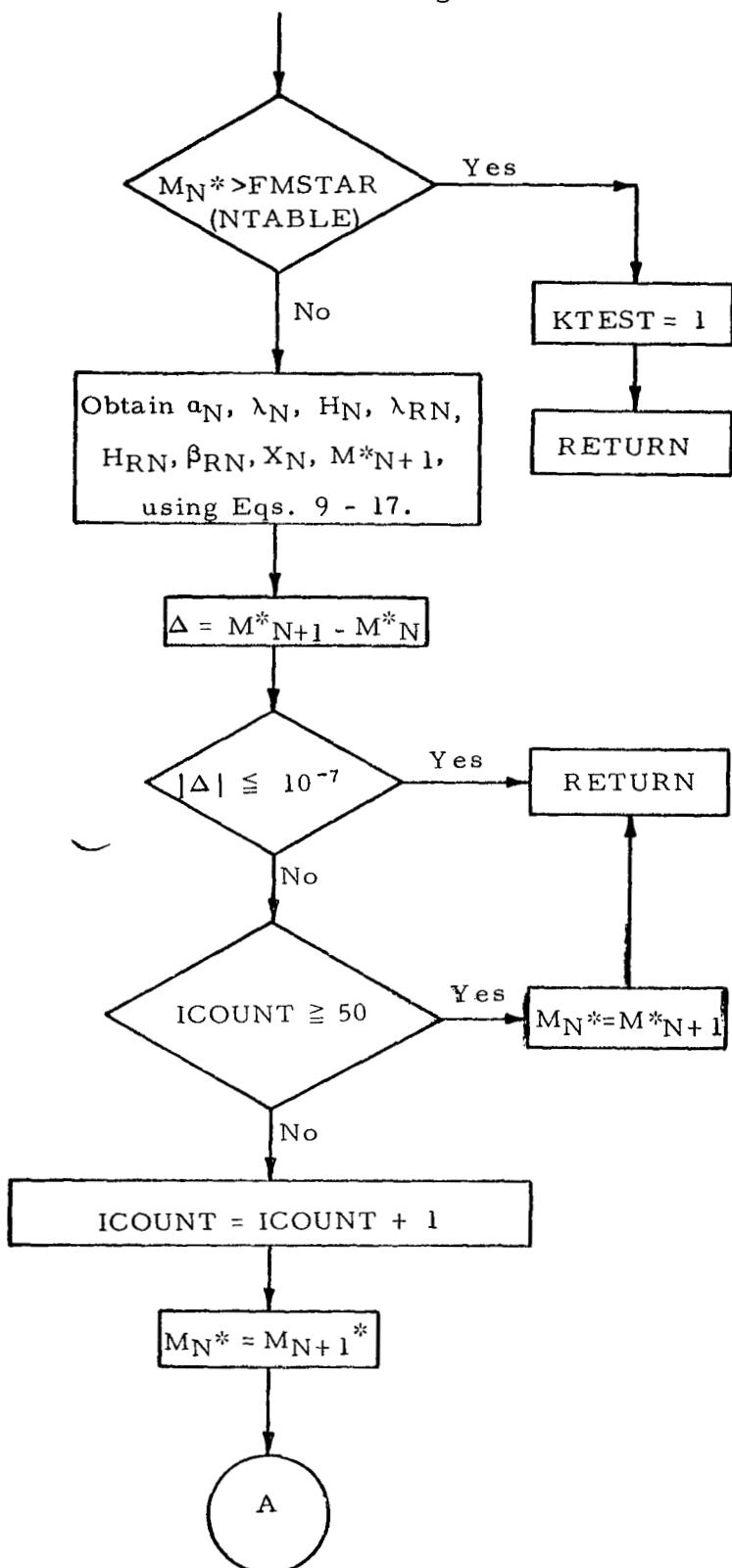


SUBROUTINE CASE3



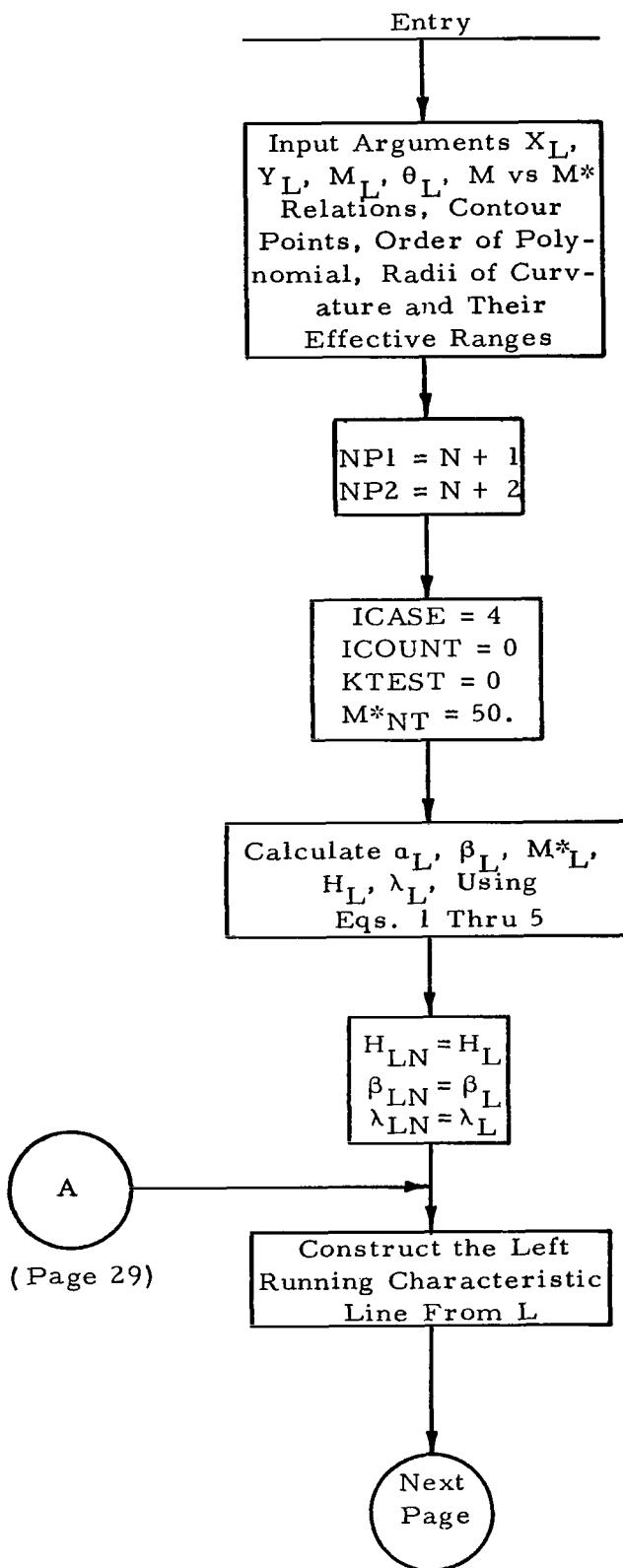


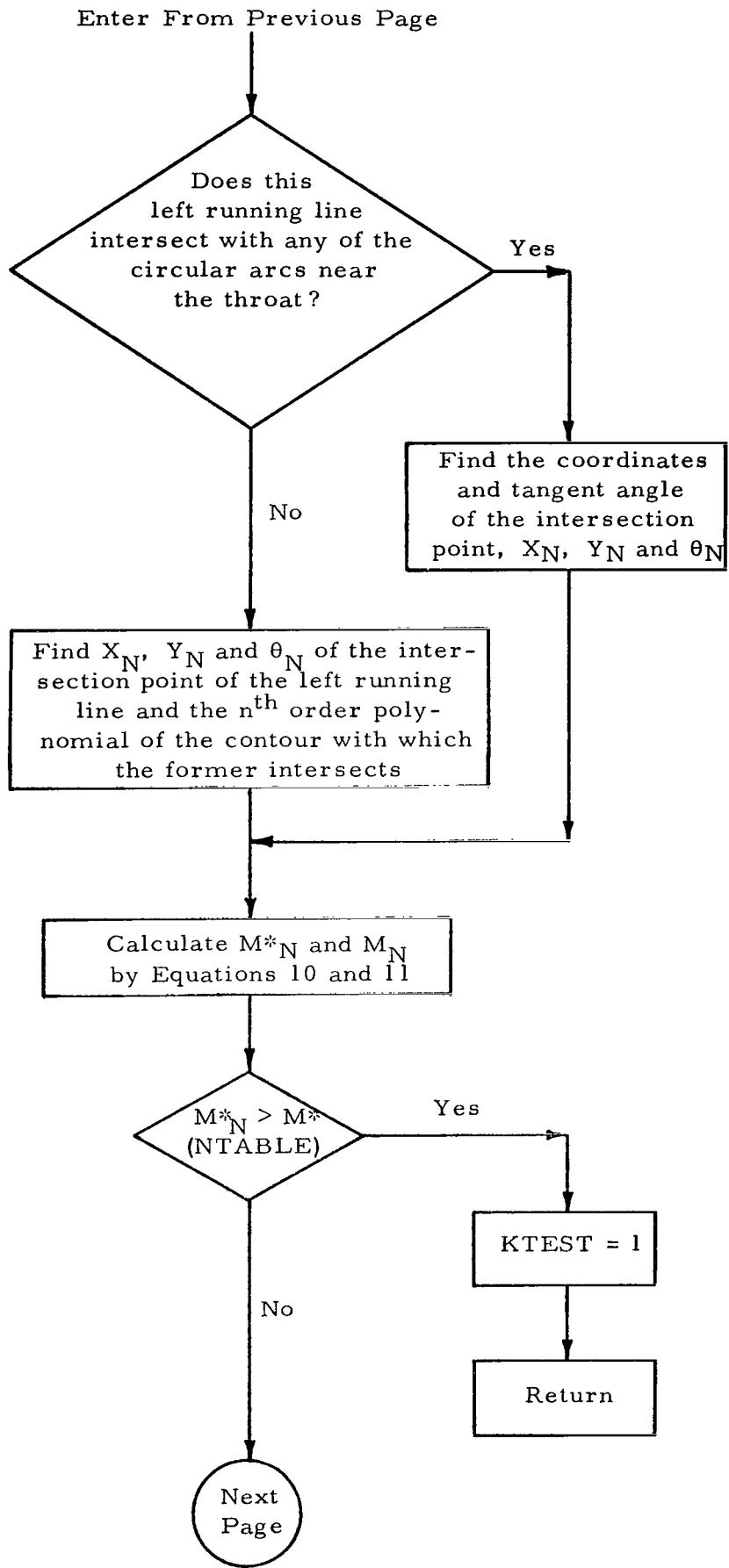
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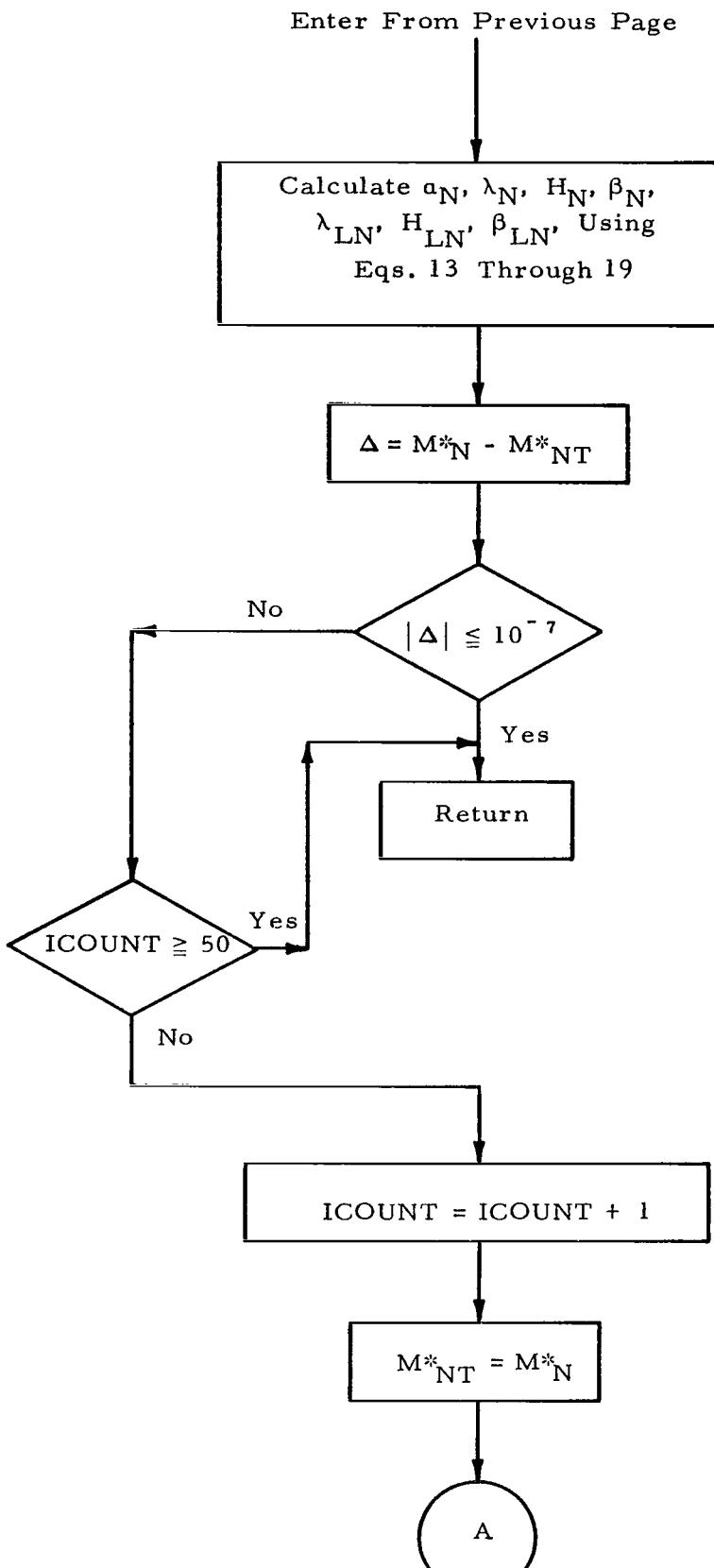


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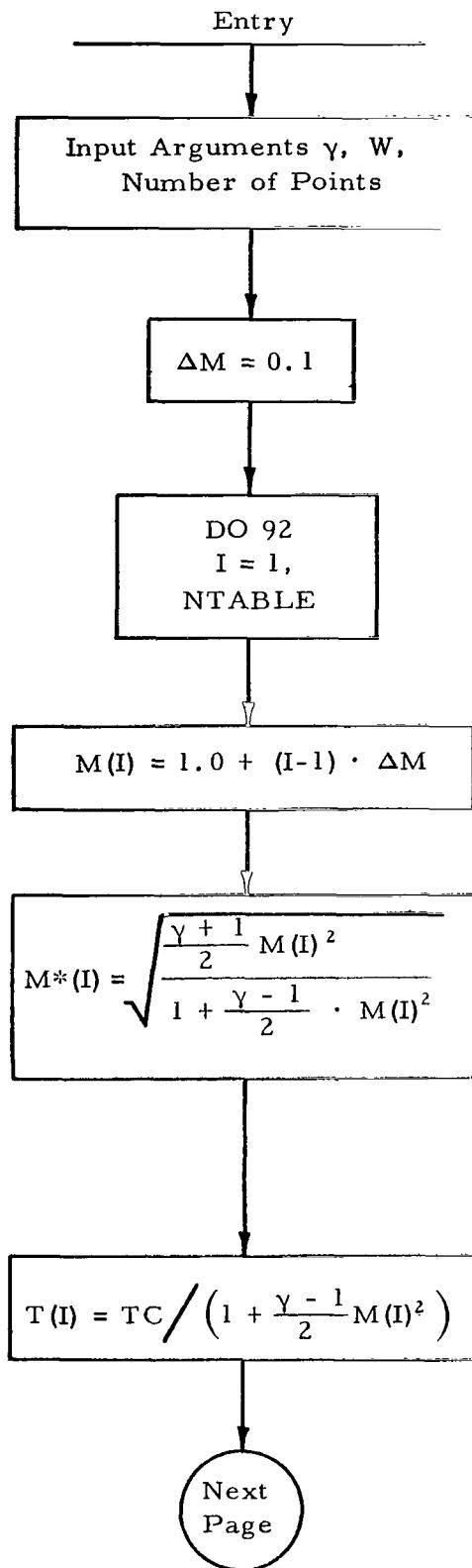
SUBROUTINE CASE4







SUBROUTINE THERMO



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$$P(I) = PC \left(1 + \frac{\gamma - 1}{2} M(I)^2 \right)^{\gamma / (\gamma - 1)}$$

$$\text{GAMMA}(I) = \gamma$$

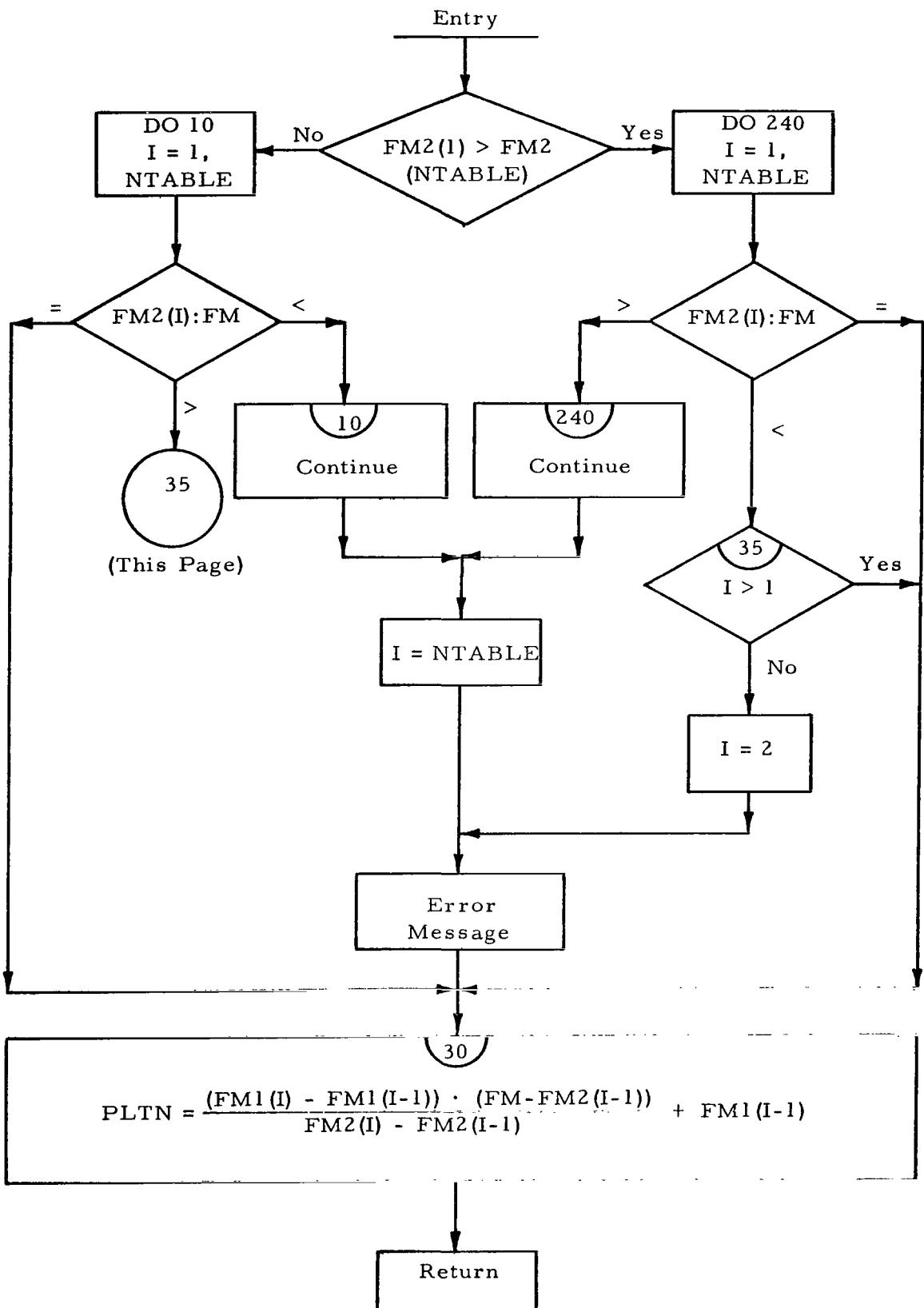
$$\text{FMW}(I) = W$$

92
Continue

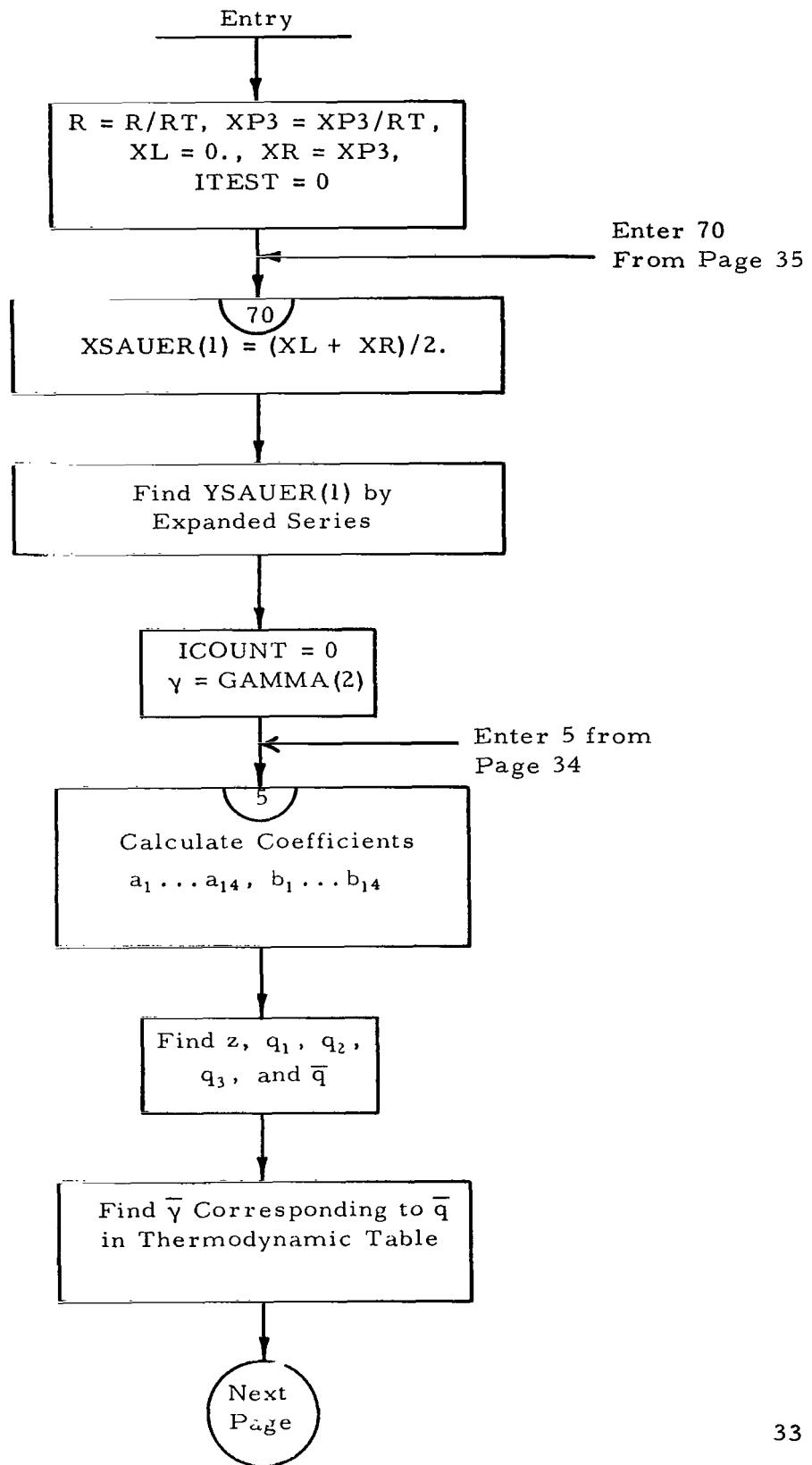
$$C^* = \sqrt{1546.336 \cdot g_c \cdot \gamma \cdot T(I)} / W$$

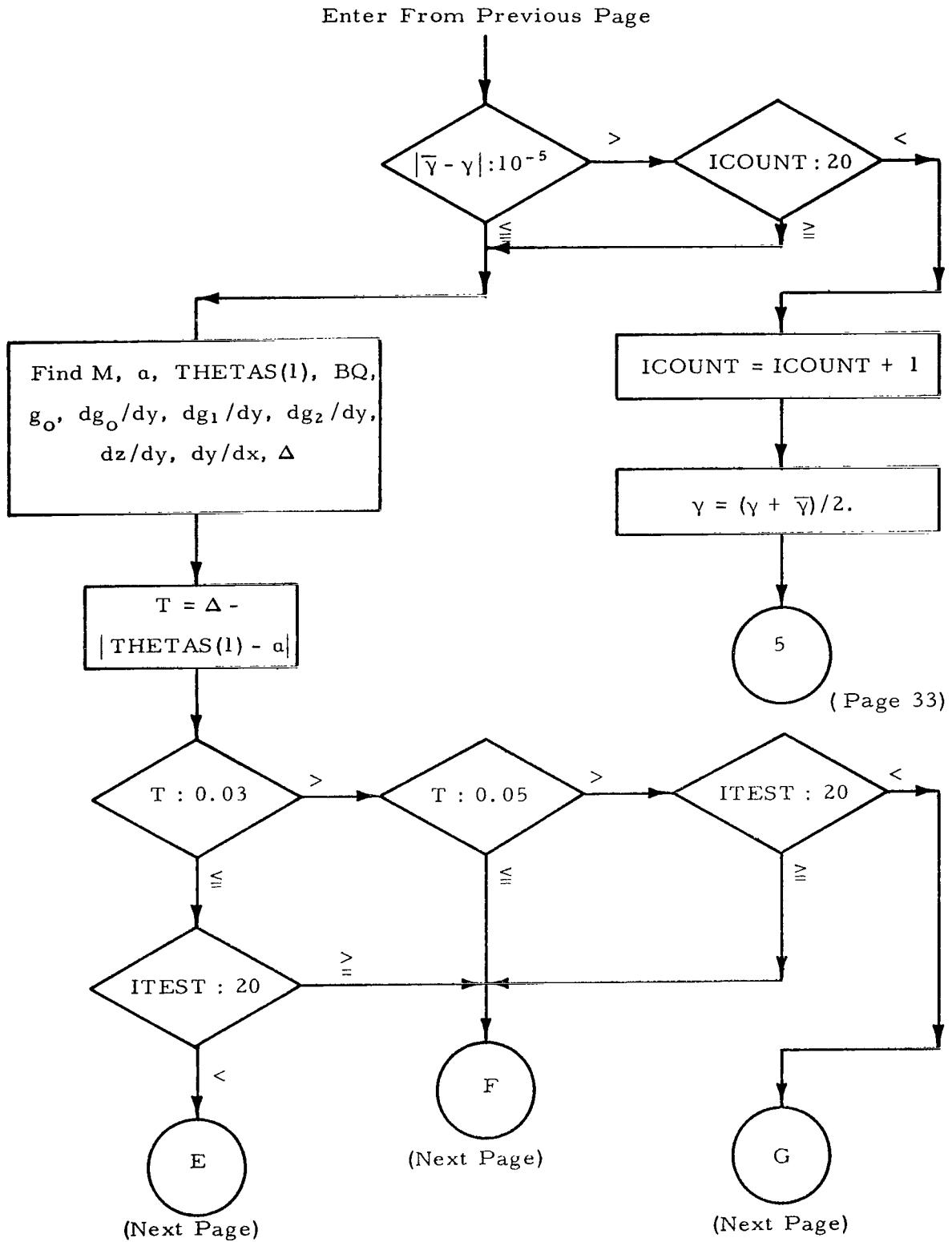
Return

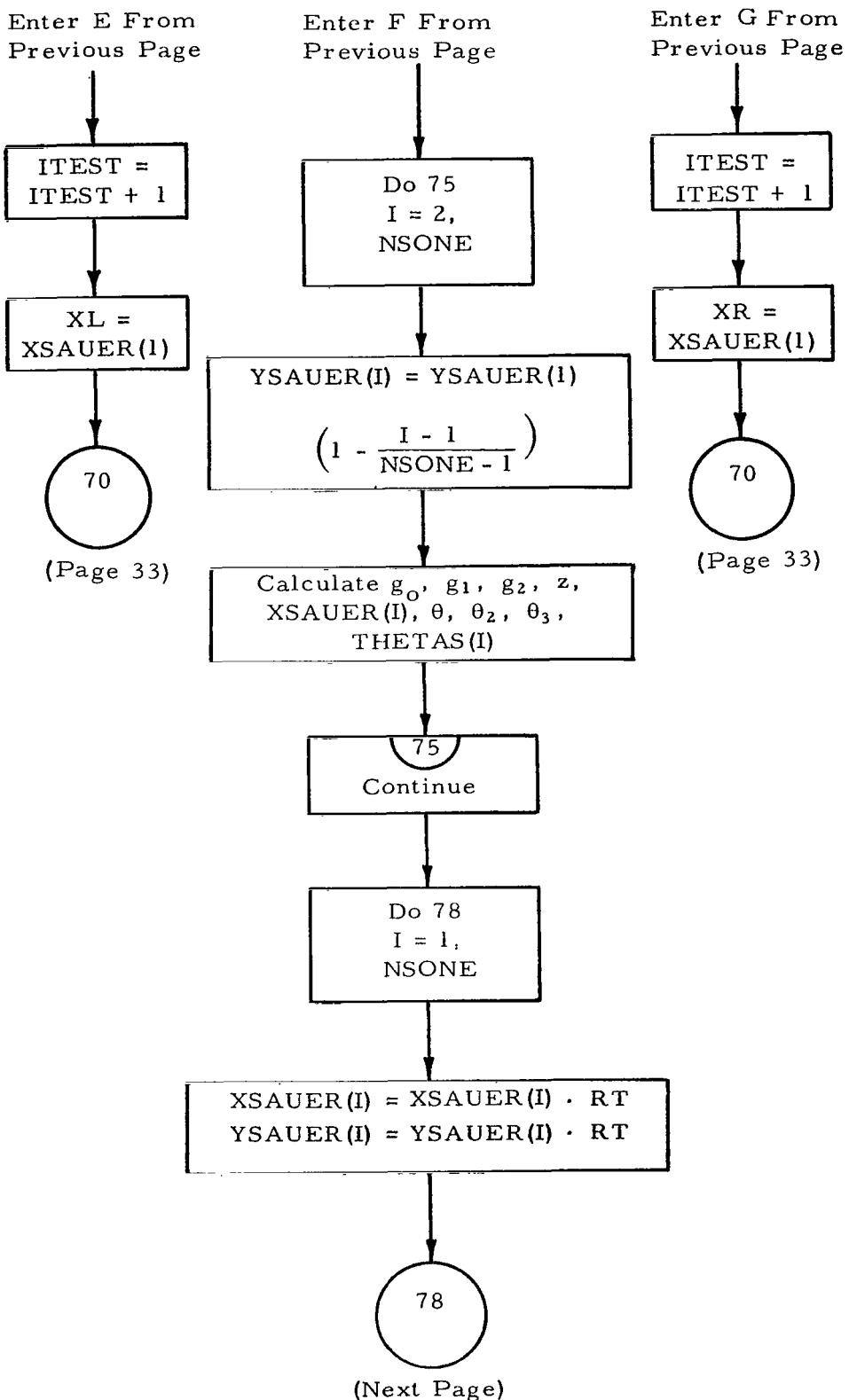
SUBROUTINE PLTN



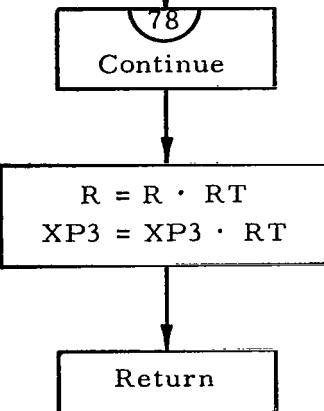
SUBROUTINE OPTIMS



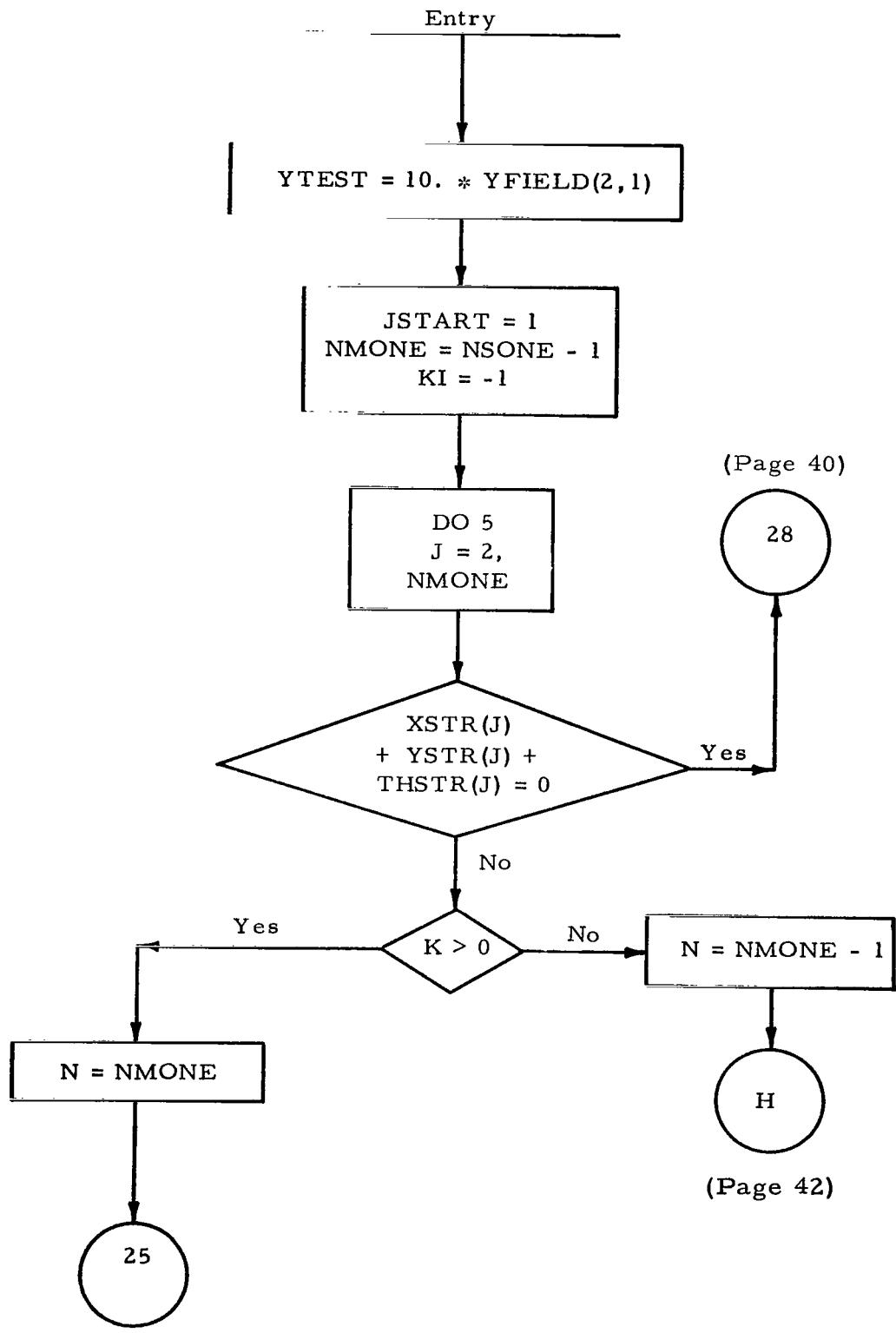




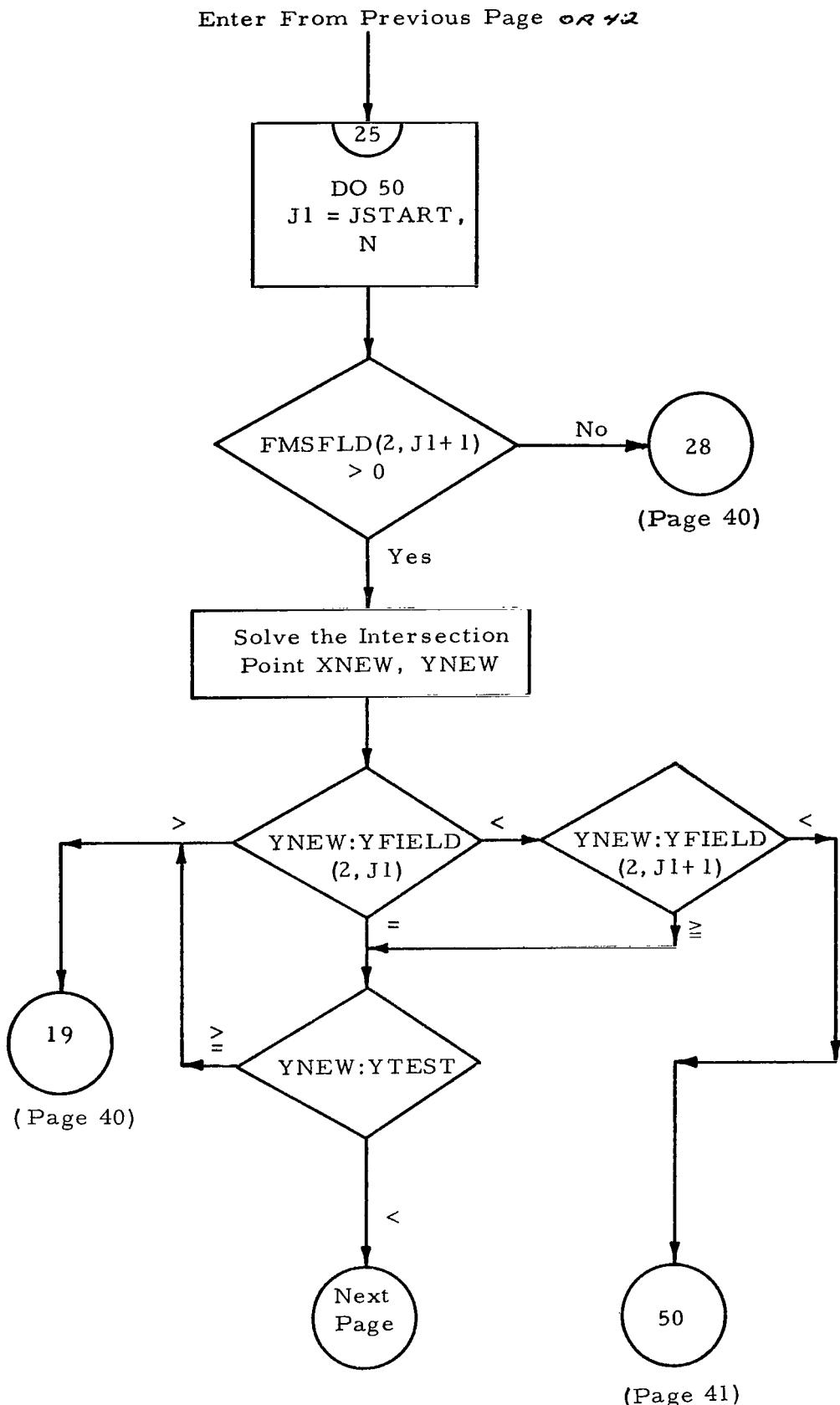
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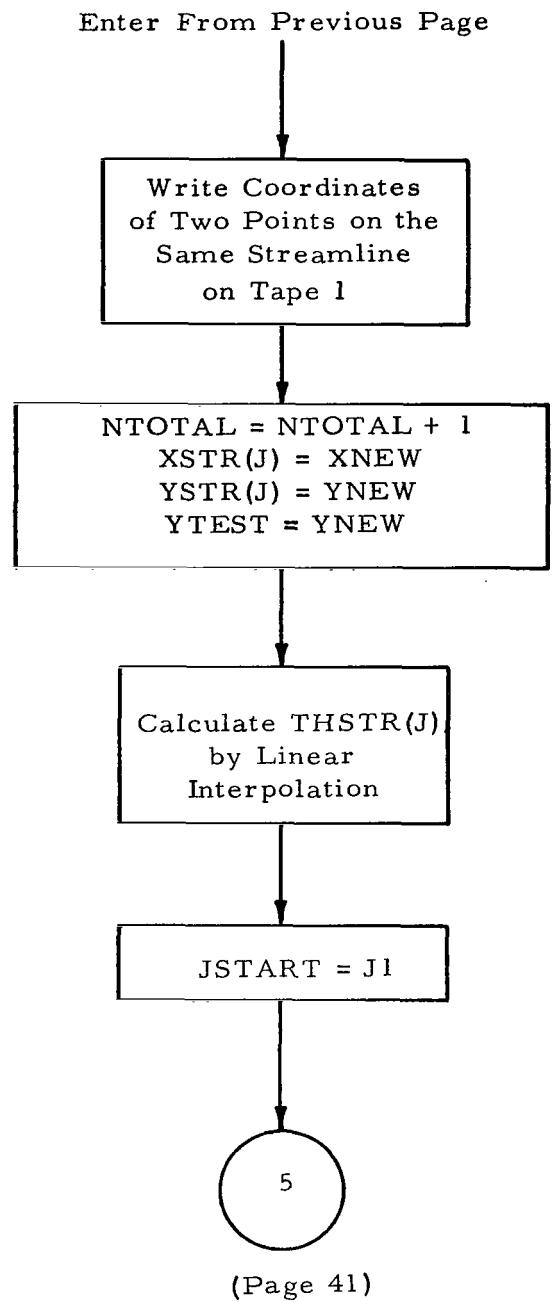


SUBROUTINE STREAM

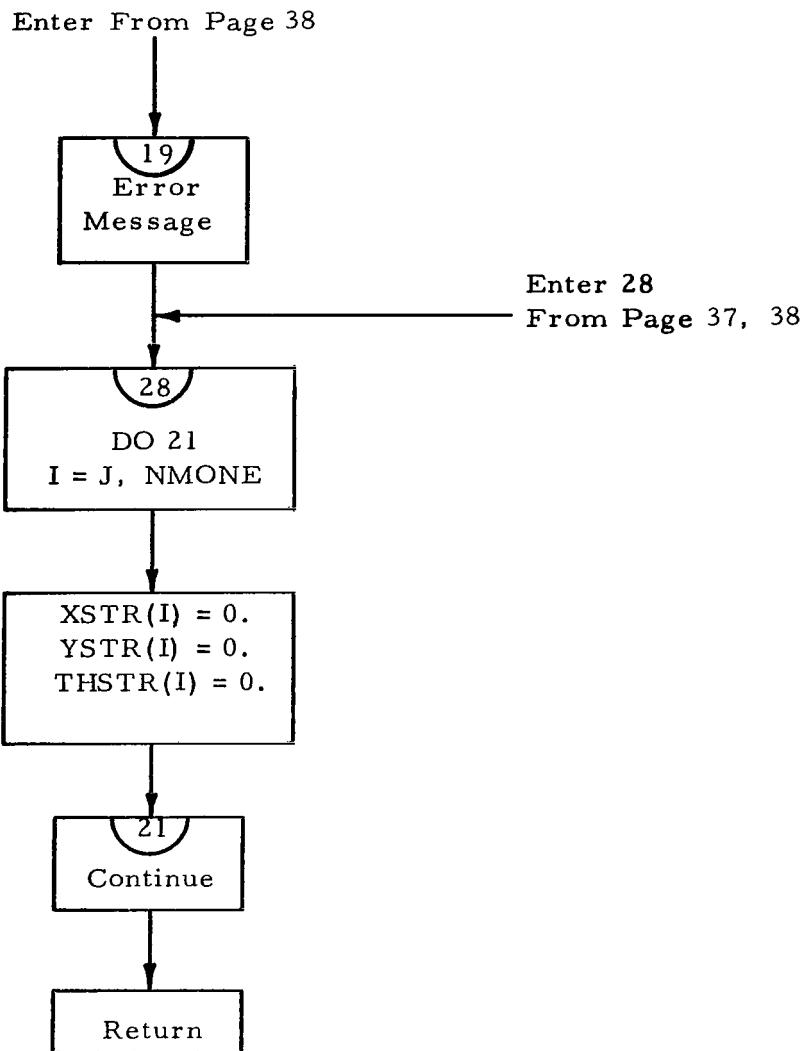


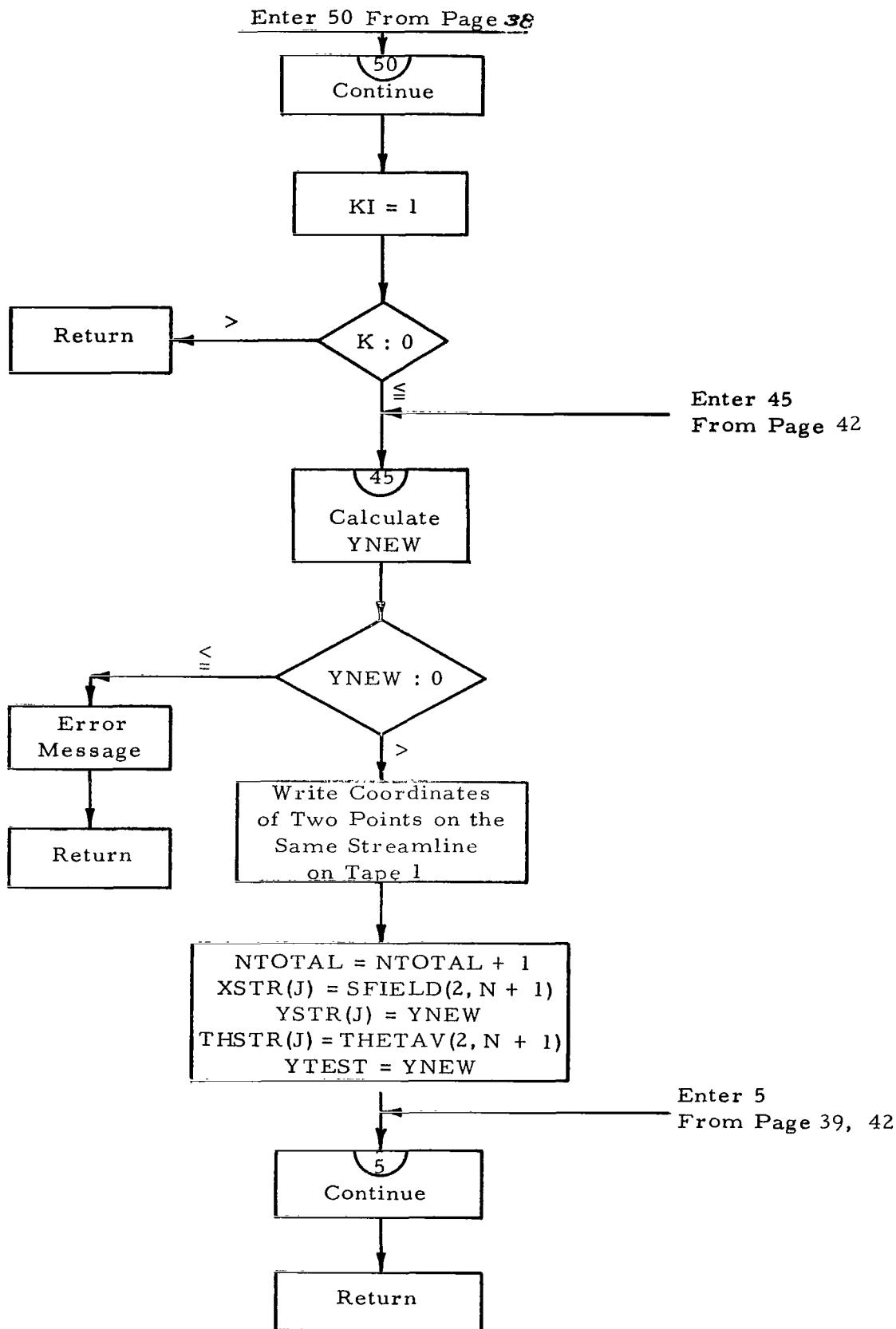
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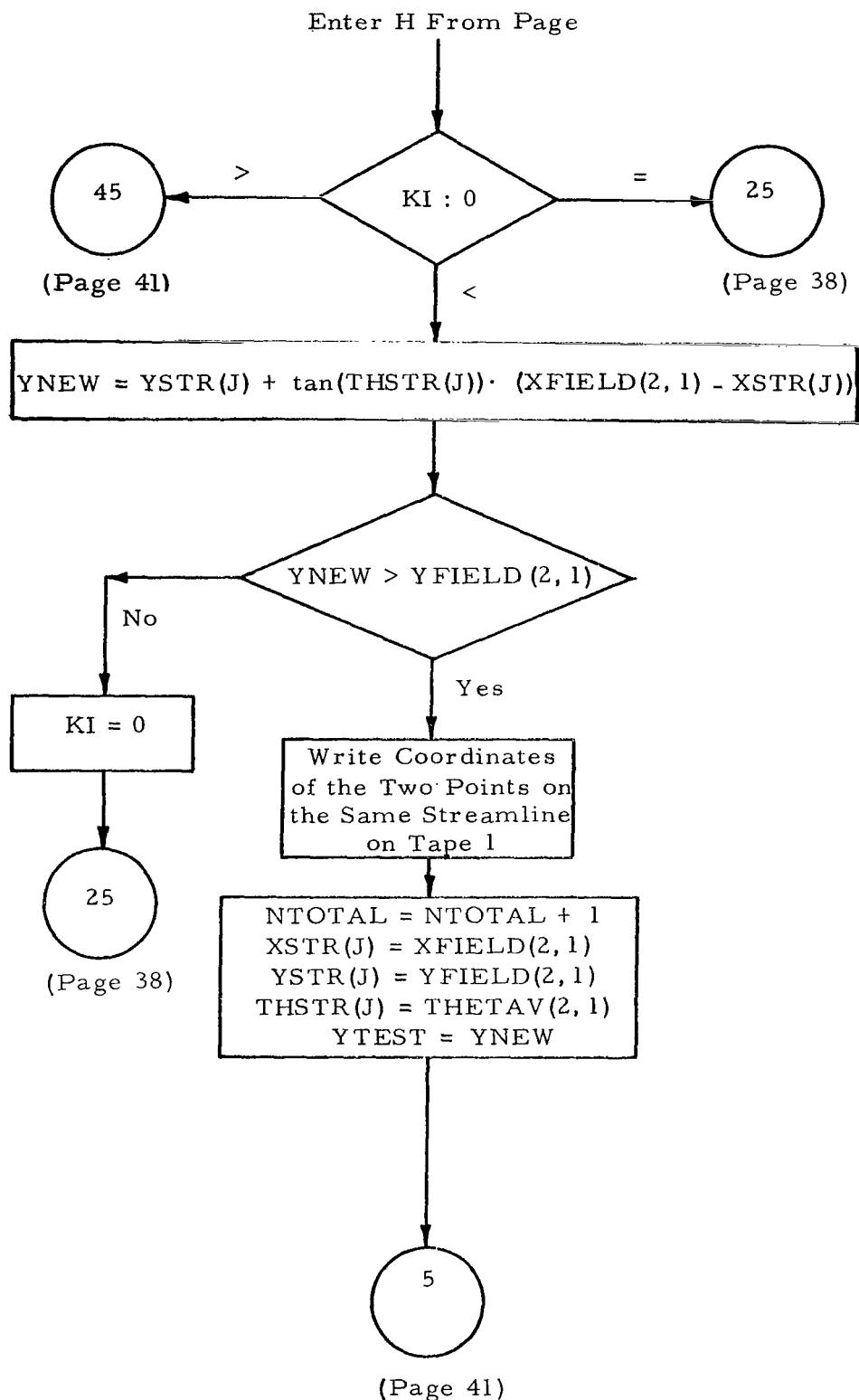




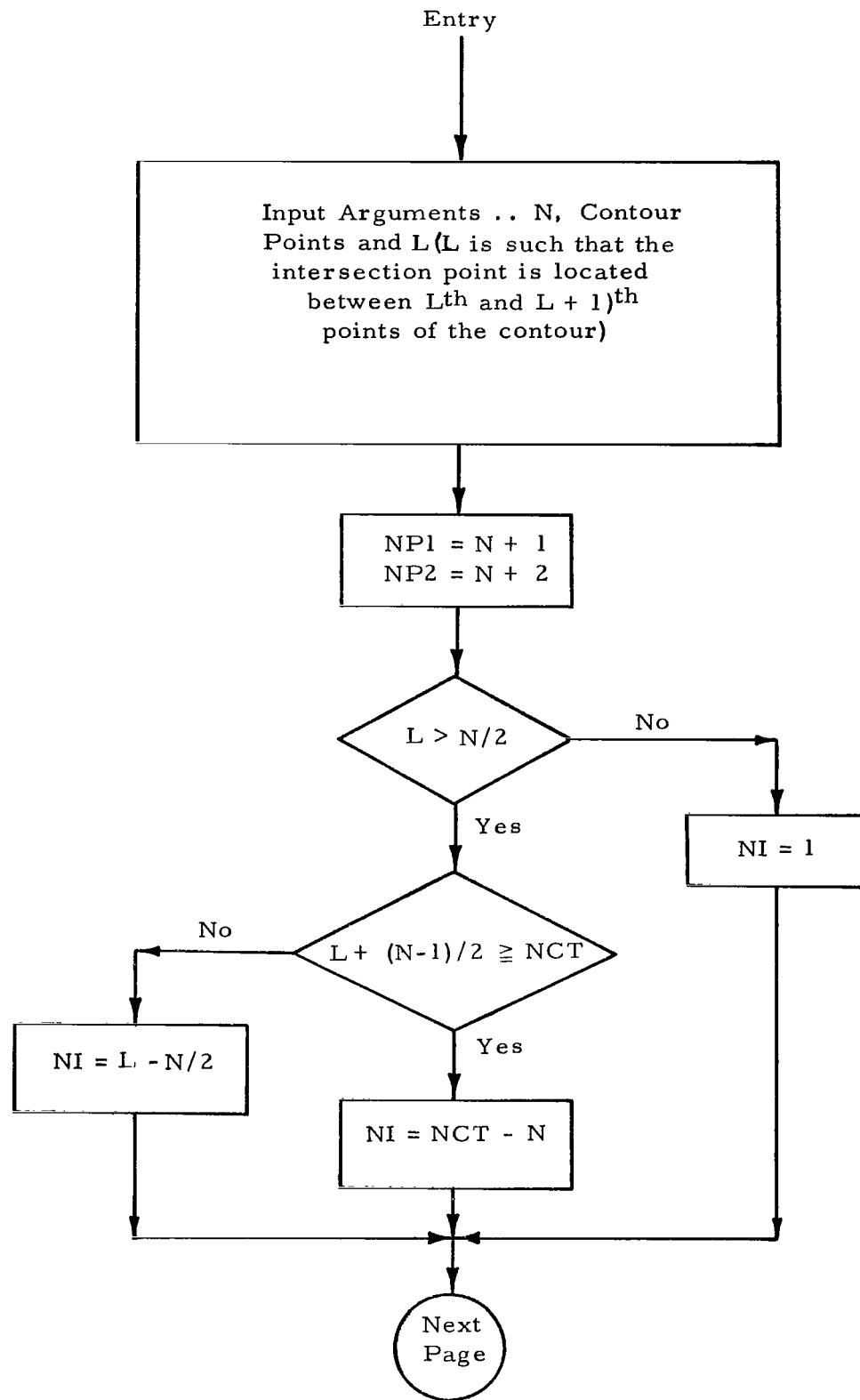
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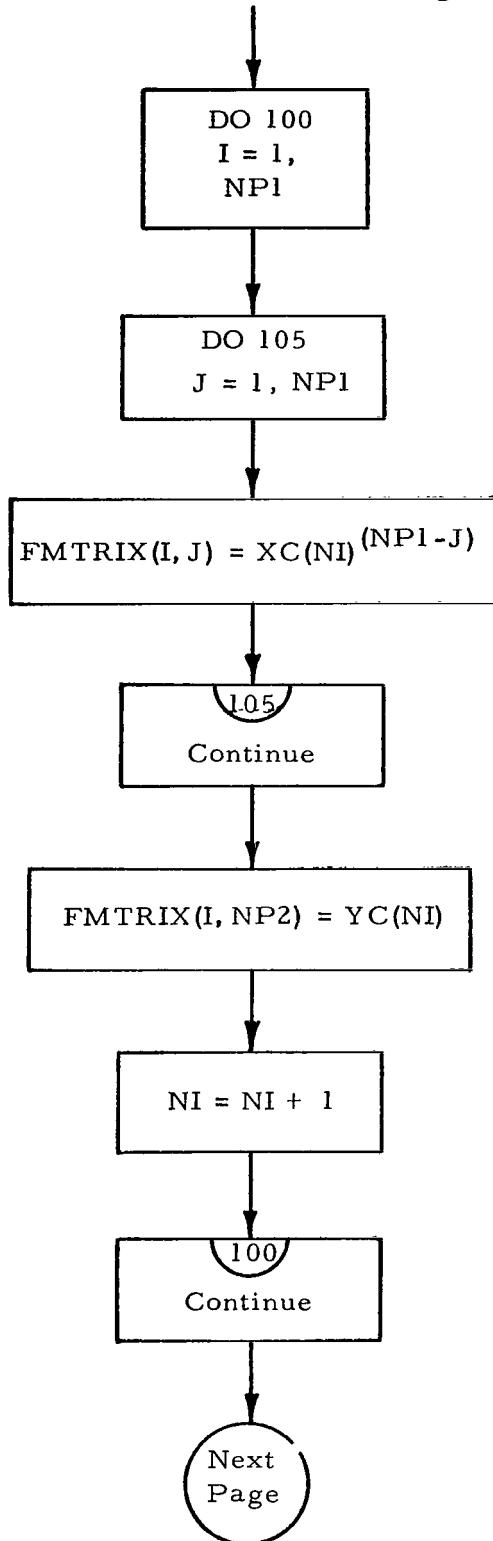




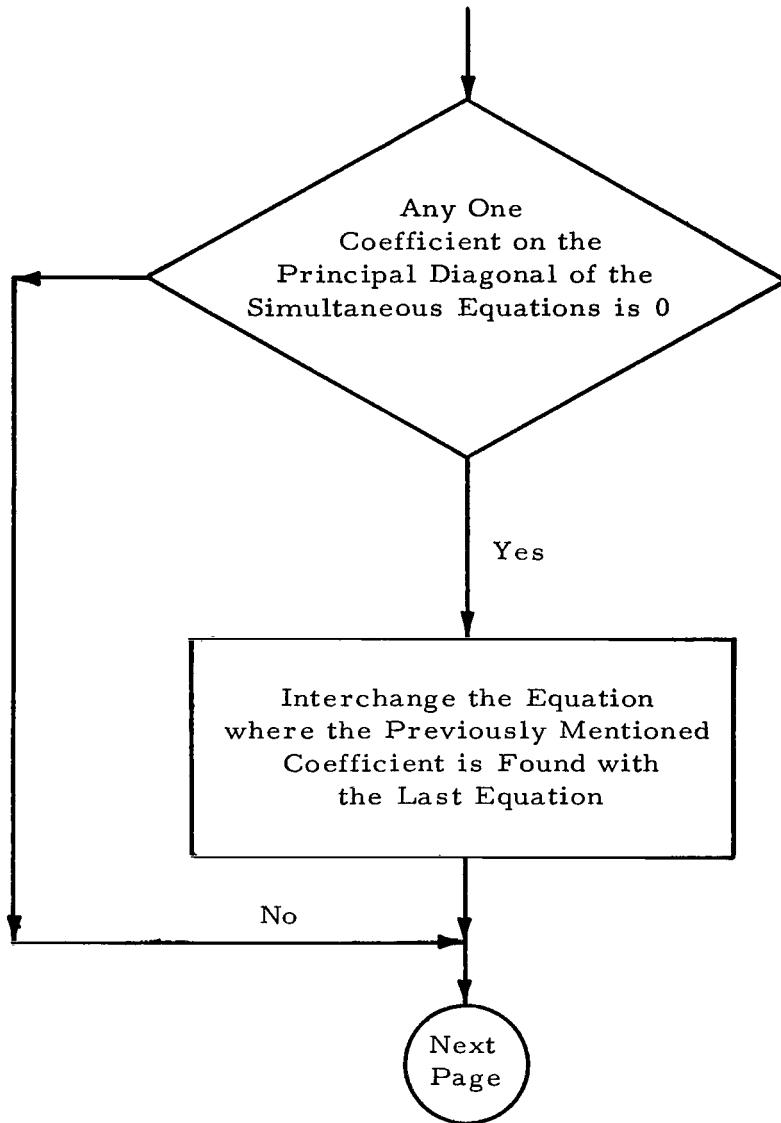
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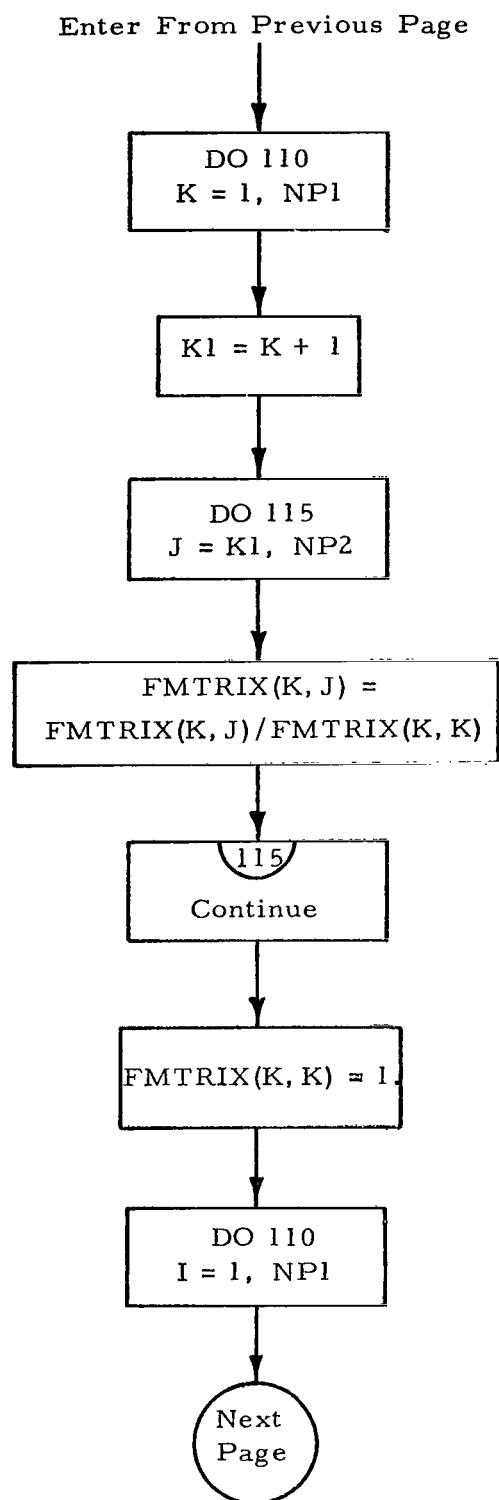


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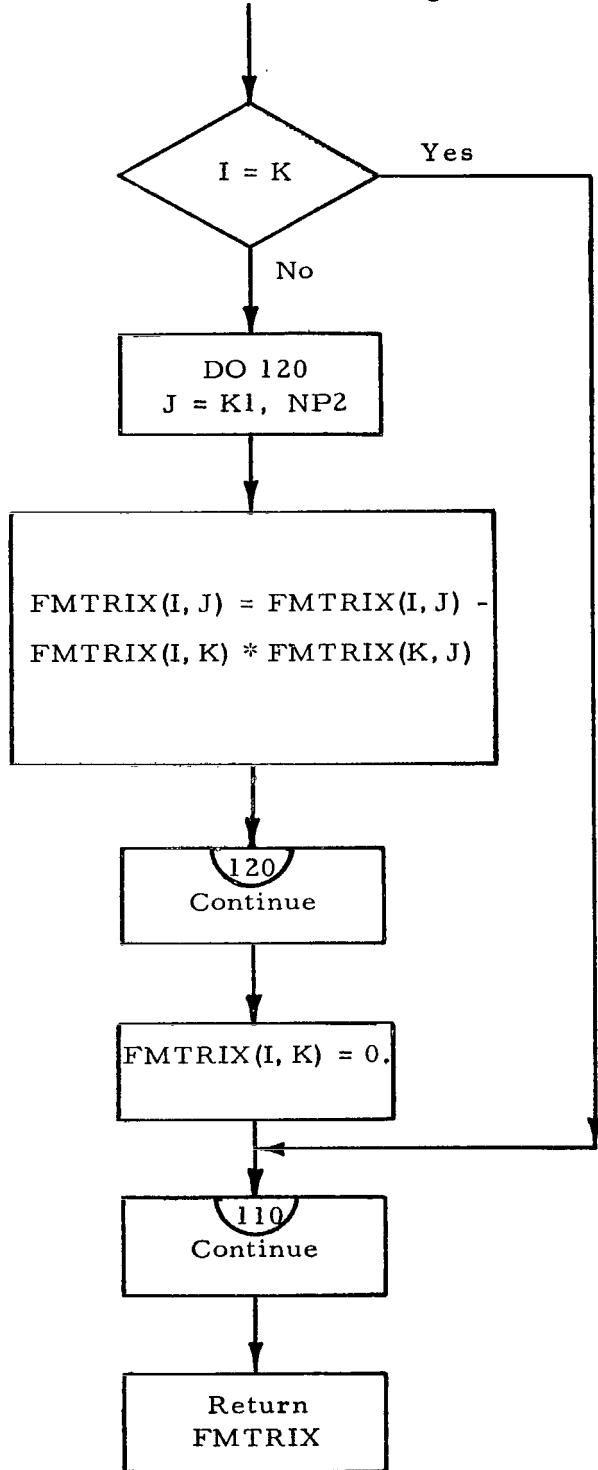


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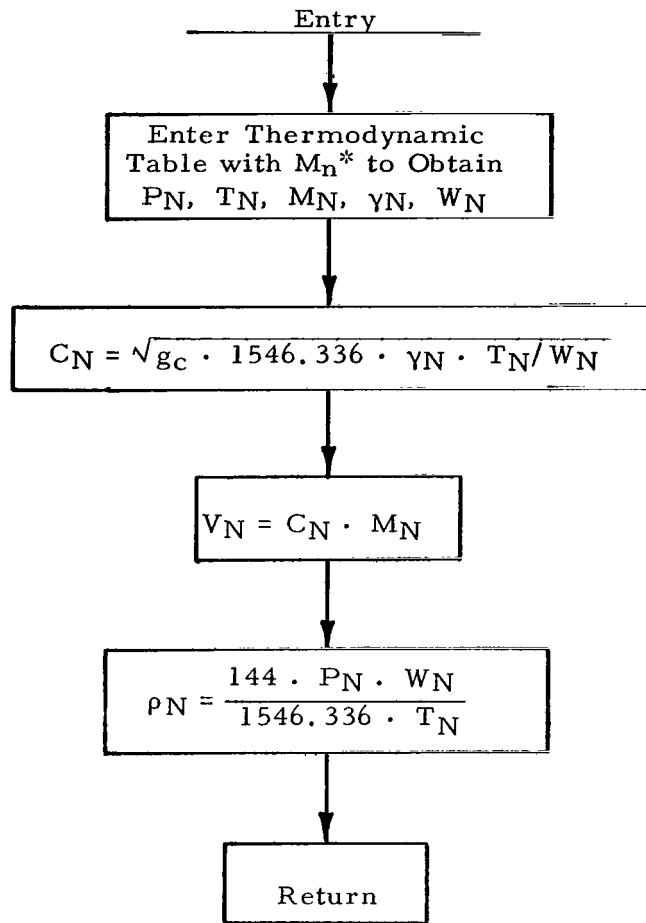




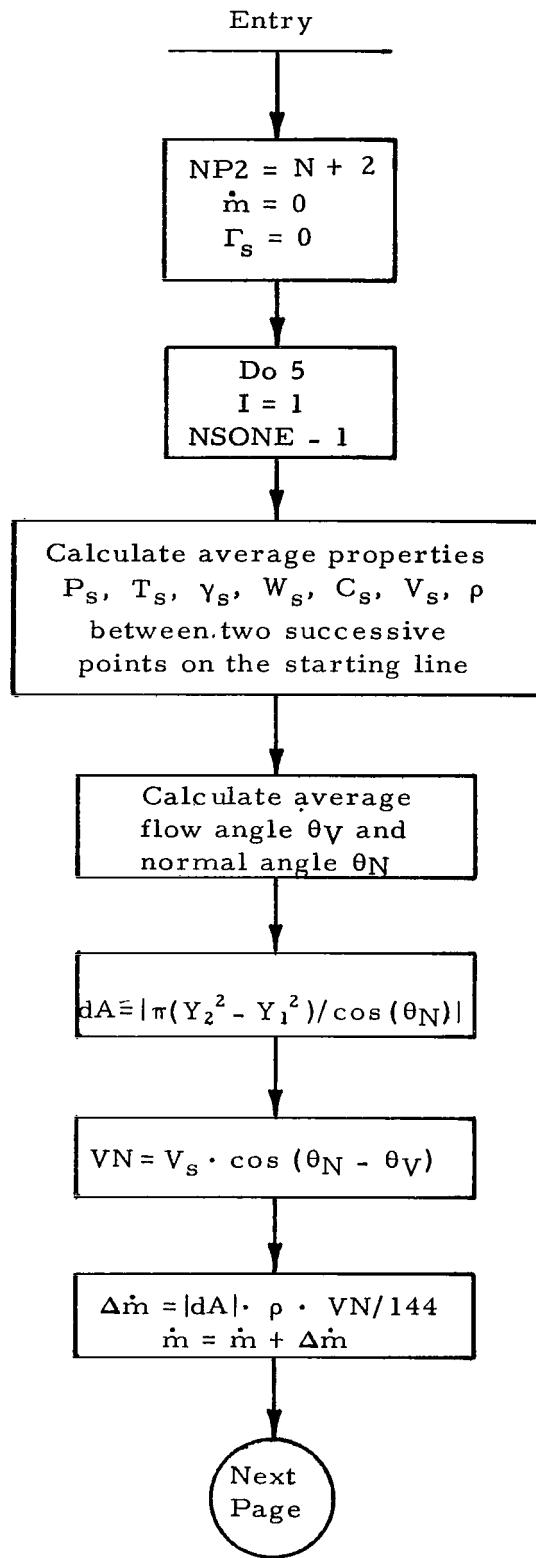
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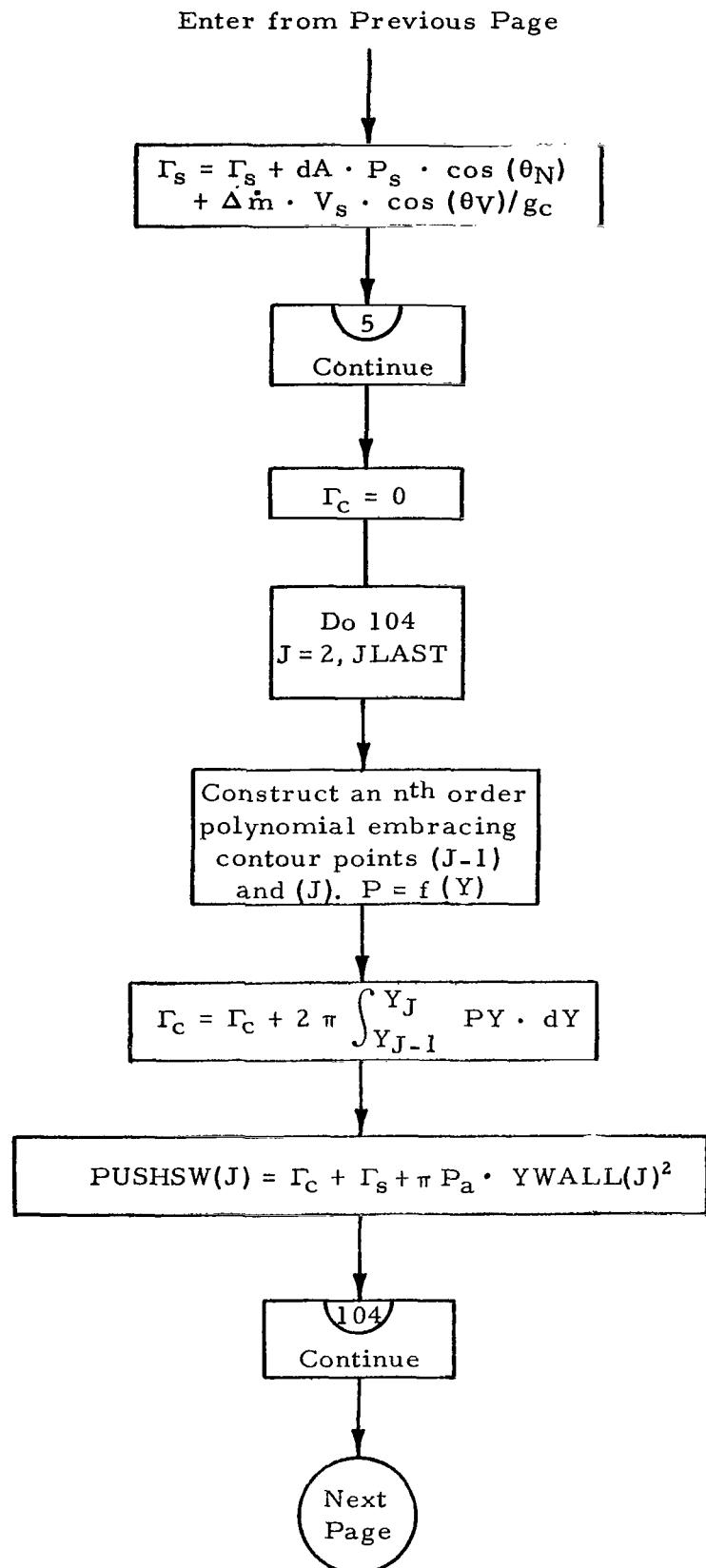


SUBROUTINE PROPTY

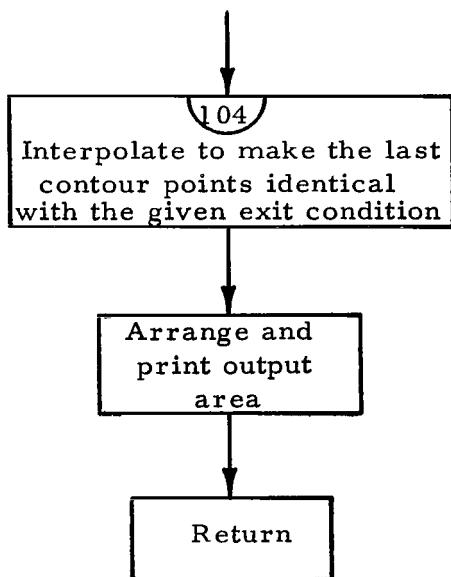


SUBROUTINE PERFOR





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FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

C

C PROGRAM SP-37 IBM 7040 COMPUTER SYSTEM AUGUST, 1963
C A FORTRAN IV COMPUTER PROGRAM TO CALCULATE FLOW PATTERN AND
C PERFORMANCE PARAMETERS FOR AXIALLY SYMMETRIC NOZZLE (BASED ON
C METHOD OF CHARACTERISTICS AND UTILIZES SC-4020 PLOTTER TO
C CONSTRUCT PLOTS OF THE CHARACTERISTIC NETWORK AND STREAMLINES.
C FLOW ASSUMED TO BE SUPERSONIC, STEADY, IRROTATIONAL, COMPRESSIBLE,
C AND SHOCK-FREE. THE CHEMICAL COMPOSITION IS ASSUMED TO BE FROZEN
C OR IN CHEMICAL EQUILIBRIUM.

C

C DEVELOPED BY THE GASDYNAMICS/THERMOCHEMISTRY LABORATORY OF
C BROWN ENGINEERING COMPANY, INC.

C

C PROGRAMMED BY CARL T.K. YOUNG

C

C

C

DIMENSION FMSTAR(80),FMVEC(80),P(80),T(80),FMW(80),
1 GAMMA(80),XWALL(250),YWALL(250),PWALL(250),FMWALL(250),
2 XSAUER(60),YSAUER(60),THETAS(60),FMSAUR(60),XFIELD(2,60),
3 YFIELD(2,60),FMSFLD(2,60),THETAV(2,60),XCWALL(250),YCWALL(250)
DIMENSION XSTR(60), YSTR(60), THSTR(60)
TAN(X) = SIN(X)/COS(X)
PI = 3.1415925636

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

REWIND 2

C

C READ IN NUMBER OF CASES TO BE RUN

C

READ (5,553) NDATA

553 FORMAT (5I5)

WRITE (2,553) NDATA

NCASE = 1

C

C KT CONTROLS INPUT OF THERMODYNAMIC DATA. KT = 1 FOR BEING
C READ IN. KT = 0 FOR ADIABATIC FLOW, WITH CONSTANT MOLECULAR
C WEIGHT AND SPECIFIC HEATS RATIO TO BE READ IN. KT = 2 FOR USING
C THE SAME THERMODYNAMIC DATA AS THE PREVIOUS RUN

C

C KC CONTROLS INPUT OF CONTOUR POINTS. KC = 1 FOR BEING READ IN.
C KC = 0 FOR USING THE SAME CONTOUR AS THE PREVIOUS RUN

C

C KS CONTROLS STARTING LINE. KS = 1 FOR BEING READ IN. KS = 0
C FOR BEING CALCULATED BY SUBROUTINE OPTIMS. KS = 2 FOR USING THE
C SAME STARTING LINE AS THE PREVIOUS RUN

C

93 READ (5,553) KT, KC, KS

C

C READ NUMBER OF INPUT POINTS OF THERMODYNAMIC DATA, ON THE
C NOZZLE CONTOUR, ON THE STARTING LINE AND THE ORDER OF POLYNOMIAL

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

C TO BE USED ON THE NOZZLE CONTOUR

C

READ (5,553) NTABLE, NCT, NSUNE, N

C

C READ AMBIENT PRESSURE, CHAMBER PRESSURE AND TEMPERATURE

C

READ (5,552) PA, PC, TC

552 FORMAT (6F10.7)

C

C READ THERMODYNAMIC DATA

C

IF (KT = 1) 754, 753, 735

753 DO 97 I = 1, NTABLE

97 READ (5,552) P(I), T(I), FMW(I), GAMMA(I), FMVEC(I), FMSTAR(I)

T1 = PLTN(1.0,T,FMVEC,NTABLE)

FMW1 = PLTN(1.0,FMW,FMVEC,NTABLE)

G1 = PLTN(1.0,GAMMA,FMVEC,NTABLE)

CSTAR = SQRT(32.174*1546.336*G1*T1/ FMW1)

GO TO 735

C

C READ SPECIFIC HEATS RATIO AND MOLECULAR WEIGHT

C

754 READ (5,552) G, W

CALL THERMO(NTABLE,G,W,PC,TC,P,T,FMW,GAMMA,FMVEC,FMSTAR,CSTAR)

735 CONTINUE

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
C  
C      READ SYMBOL AND SCALES OF COORDINATES TO BE USED FOR SC-4020  
C      PLOTTER  
  
C      READ (5,511) ISYM, XCL, XCR, YCB, YCT  
511 FORMAT (I10,4F10.5)  
      WRITE (2,511) ISYM, XCL, XCR, YCB, YCT  
  
C      READ DIFFERENT RADII AND THEIR RANGES OF THE NOZZLE WALL  
C      IN THE NEIGHBORHOOD OF THE THROAT  
  
C      READ (5,552) RNX1, RNX2, RPX1, RPX2, RPX3  
      READ (5,552) XN1, XN2, XP1, XP2, XP3  
  
C      READ THROAT RADIUS, AREA RATIO, NOZZLE LENGTH AND A SPECIAL  
C      FACTOR WHICH DECIDES THE CUT-OFF POINT ON THE AXIS  
  
C      READ (5,552) RT, ARATIO, XNLTH, ANL  
  
C      READ POINTS ON THE NOZZLE CONTOUR  
  
C      IF (KC) 921, 921, 922  
922 DO 705 I = 1, NLT  
705 READ (5,552) XWALL(I), YWALL(I)  
921 IF (KS - 1) 734, 733, 742
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
734 READ (5,552) SIGMA
      CALL OPTIMS(SIGMA,RPX3,FMVEC,FMSTAR,GAMMA,NTABLE,XP3,FMSUER,RT,
1 NSONE,XSAUER,YSAUER,THETAS)
      DO 27 J = 1, NSONE
27 FMSAUR(J) = FMSUER
      GO TO 742
733 DO 704 J = 1, NSONE
      READ (5,552) XSAUER(J), YSAUER(J), THETAS(J), FMSAUR(J)
      THETAS(J) = THETAS(J) * PI / 180.
704 CONTINUE
      FMSUER = FMSAUR(1)
742 CONTINUE
      YEXIT = RT * SQRT(ARATIO)
      XT = 0.
C
C      PRINT INPUT DATA
C
      WRITE (6,600)
600 FORMAT (1H1,5X,25HINPUT DATA ARE AS FOLLOWS//)
      WRITE (6,601) PA
601 FORMAT (1H0,10X,22HAMBIENT PRESSURE, PA =,F12.7,5H PSIA)
      WRITE (6,602) PC
602 FORMAT (1H0,10X,22HCHAMBER PRESSURE, PC =,F12.7,5H PSIA)
      WRITE (6,675) TC
675 FORMAT (1H0,7X,25HCHAMBER TEMPERATURE, TC =,F12.7,9H DEGREE R)
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
      WRITE (6,603) RT
603 FORMAT (1H0,13X,19HTHROAT RADIUS, RT =,F12.7,4H IN.)
      WRITE (6,617) XNLTH
617 FORMAT (1H0,10X,22HNOZZLE LENGTH, XNLTH =,F12.7,4H IN.)
      WRITE (6,604) ARATIO
604 FORMAT (1H0,13X,19HAREA RATIO, AE/AT =,F12.7)
      WRITE (6,605)
605 FORMAT (1H0,10X,44HRADII OF THE NOZZLE WALL IN THE NEIGHBORHOOD,
1 24H OF THE THROAT, ASSUMING/11X,24HALL THE CENTERS OF RADII,
2 46H LIE ON THE Y-AXIS, AND THEIR EFFECTIVE RANGES//)
      WRITE (6,606) RNX1, XN1, XN2
      WRITE (6,606) RNX2, XN2, XT
      WRITE (6,606) RPX1, XT, XP1
      WRITE (6,606) RPX2, XP1, XP2
      WRITE (6,606) RPX3, XP2, XP3
606 FORMAT (11X,8HRADIUS =,F10.7,1X,3HIN.,1X,13HFOR X BETWEEN,F12.7,
1 1X,3HIN.,1X,3HAND,3X,F10.7,4H IN.)
      WRITE (6,609)
609 FORMAT (1H1,7X,18HTHERMODYNAMIC DATA///16X,8HPRESSURE,5X,
1 11HTEMPERATURE,3X,12HMOLECULAR WT,5X,8HSPECIFIC,6X,7HMACH NO,
2 9X,2HM*/17X,6H(PSIA),7X,10H(DEGREE R),3X,12H(LB/LB-MORE),3X,
3 11HHHEATS RATIO//)
      J = 1
      DO 95 I = 1, NTABLE
      IF (I - 50 * J) 95, 95, 331
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
331 WRITE (6,662)

      J = J + 1

 95 WRITE (6,610) P(I), T(I), FMW(I), GAMMA(I), FMVEC(I), FMSTAR(I)
610 FORMAT (1IX,F14.7,F15.7,4F14.7)
662 FORMAT (1H1)

      WRITE (6,619) CSTAR
619 FORMAT (///10X,29HCRITICAL SONIC VELOCITY, C* =,F14.7,7H FT/SEC)

      WRITE (6,607)

607 FORMAT (1H1,7X,34HPOINTS DEFINING THE NOZZLE CONTOUR //1H0,17X,
1 1HX,11X,1HY/16X,5H(IN.),7X,5H(IN.)/)

      DO 94 I = 1, NCT

 94 WRITE (6,608) XWALL(I), YWALL(I)
608 FORMAT (1IX,2F12.7)

      DO 96 J = 1, NSONE

      XFIELD(I,J) = XSAUER(J)
      YFIELD(I,J) = YSAUER(J)
      THETAV(I,J) = THETAS(J)

 96 FMSFLD(I,J) = PLTN(FMSAUR(J),FMSTAR,FMVEC,NTABLE)

      WRITE (6,611)

611 FORMAT (1H1,7X,27HPOINTS ON THE STARTING LINE//)
      IF (FMSAUR(1) - FMSAUR(NSONE)) 743, 744, 743

744 CONTINUE

      FMSSER = PLTN(FMSUER,FMSTAR,FMVEC,NTABLE)
      PSAUER = PLTN(FMSUER,P,FMVEC,NTABLE)
      TSAUER = PLTN(FMSUER,T,FMVEC,NTABLE)
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
FMWS=PLTN(FMSUER,FMW,FMVEC,NTABLE)
GSAUER = PLTN(FMSUER,GAMMA,FMVEC,NTABLE)
CSAUER = SQRT(32.174*1546.336*GSAUER*TSAUER/FMWS)
VSAUER = CSAUER * FMSUER
RHU = 144.0 * PSAUER * FMWS / (1546.336 * TSAUER)
WRITE (6,612) FMSUER
612 FORMAT (1H0,21X,10HMACH NO. =,F14.7)
WRITE (6,681) FMSER
681 FORMAT (28X,4HM* =,F14.7)
WRITE (6,614) GSAUER
614 FORMAT (11X,21HSPECIFIC HEAT RATIO =,F14.7)
WRITE (6,613) PSAUER
613 FORMAT (22X,10HPRESSURE =,F14.7,5H PSIA)
WRITE (6,684) TSAUER
684 FORMAT (19X,13HTEMPERATURE =,F14.7,9H DEGREE R)
WRITE (6,682) CSAUER
682 FORMAT (16X,16HSONIC VELOCITY =,F14.7,7H FT/SEC)
WRITE (6,683) VSAUER
683 FORMAT (22X,10HVELOCITY =,F14.7,7H FT/SEC)
WRITE (6,689) RHU
689 FORMAT (23X,9HDENSITY =,F14.7,10H LB/M CU-FT)
WRITE (6,685) FMWS
685 FORMAT (14X,18HMOLECULAR WEIGHT =,F14.7,12H LB/LB-MOLE)
WRITE (6,615)
615 FORMAT (//1H0,18X,1HX,11X,1HY,9X,5HTHETA/17X,5H(IN.),7X,5H(IN.),
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
1 5X,9H(DEGREES)//  
DO 32 J = 1, NSUNE  
THETAS(J) = THETAS(J) * 180. / PI  
WRITE (6,616) XSAUER(J), YSAUER(J), THETAS(J)  
32 THETAS(J) = THETAS(J) * PI / 180.  
616 FORMAT (12X,4F12.7)  
GO TO 747  
743 CONTINUE  
WRITE (6,6115)  
6115 FORMAT (1H0,18X,1HX,11X,1HY,9X,5HTHETA,9X,1HM/17X,5H(IN.),7X,  
1 5H(IN.),5X,9H(DEGREES//)  
DO 31 J = 1, NSUNE  
THETAS(J) = THETAS(J) * 180. / PI  
WRITE (6,616) XSAUER(J), YSAUER(J), THETAS(J), FMSAUR(J)  
31 THETAS(J) = THETAS(J) * PI / 180.  
747 CONTINUE  
NMUNE = NSUNE - 1  
DO 241 J = 2, NMUNE  
XSTR(J) = XSAUER(J)  
YSTR(J) = YSAUER(J)  
241 THSTR(J) = THETAS(J)  
WRITE (6,671)  
671 FORMAT (1H1,1X,35HCALCULATED POINTS ARRANGED ROW WISE//  
1 3X,1H1,2X,1HJ,7X,1HX,10X,1HY,10X,1HM,10X,2HM*,7X,5HTHETA,8X,1HT,  
2 8X,1HP,8X,1HV,5X,7HDENSITY,3X,9HTOLERANCE,2X,9HITERATION,2X,
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
3 SHERROR/12X,5H(IN.),6X,5H(IN.),28X,5H(DEG),5X,7H(DEG R),2X,
4 6H(PSIA),2X,8H(FT/SEC),1X,10H(LB/CU-FT),21X,9HINDICATOR//)

C
C      CALCULATE FIELD POINTS
C

      WRITE (2,276) NSONE, (XSAUER(J), YSAUER(J), J = 1, NSONE)

276 FORMAT (I10/(12F10.6))

      REWIND 1

      NTOTAL = 0

      NPRINT = 0

      JLAST = 1

      KCHECK = 1

      DO 78 J = 1, NSONE

78 FMSFLD(2,J) = 0.

      I = 1

44 JEND = NSONE - 1

45 DO 20 J = 1, JEND

      IF (FMSFLD(1,J+1)) 1002, 1002, 301

301 IF (FMSFLD(1,J)) 1002, 1002, 321

      XR = XFIELD(1,J)

      YR = YFIELD(1,J)

      FMSR = FMSFLD(1,J)

      FMR = PLTN(FMSR,FMVEC,FMSTAR,NTABLE)

      THETAR = THETAV(1,J)

      XL = XFIELD(1,J+1)
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PRUGRAM

```
YL = YFIELD(1,J+1)
FMSL = FMSFLD(1,J+1)
FML= PLTN(FMSL,FMVEC,FMSTAR,NTABLE)
THETAL = THETAV(1,J+1)

IF (XL - XNLTH) 303, 303, 322
303 IF (XR - XNLTH) 302, 302, 1002
322 IF (J - 1) 302, 302, 1002
302 IF (YL) 5, 5, 10

10 CALL CASE1(XR,YR,FMR,THETAR,XL,YL,FML,THETAL,FMSTAR,FMVEC,
1 NTABLE,XN,YN,FMSN,THETAN,DELTA,ICASE,ICOUNT,KTEST)
GO TO 306

5 CALL CASE2(XR,YR,FMR,THETAR,XL,YL,FML,THETAL,FMSTAR,FMVEC,
1 NTABLE,XN,YN,FMSN,THETAN,DELTA,ICASE,ICOUNT,KTEST)

306 IF (KTEST) 1001, 1001, 1002
1002 FMN = 0.
FMSN = 0.
PN = 0.
TN = 0.
VN = 0.
RHUN = 0.
GO TO 18

1001 CALL PROPTY(FMSN,P,T,FMW,GAMMA,FMVEC,FMSTAR,NTABLE,PN,TN,VN,
1 RHUN,FMN)
WRITE (2,552) XR, YR, XN, YN
WRITE (2,552) XL, YL, XN, YN
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```

18 II = I + 1

J1 = (I/2) * 2 - 1 + J + 1

XFIELD(2,J1) = XN

YFIELD(2,J1) = YN

FMSFLD(2,J1) = FMSN

THETAV(2,J1) = THETAN

IF (FMSFLD(1,J+1)) 20, 20, 2007

2007 IF (FLOAT(KTEST) + FMN) 20, 20, 2211

2211 NPRINT = NPRINT + 1

    THETAN = THETAN * 180. / PI

    IF (NPRINT = 52) 811, 811, 812

812 NDEL = NPRINT - 53 - 56*((NPRINT-52)/56)

    IF (NDEL) 811, 813, 811

813 WRITE (6,686)

686 FORMAT (1HL,2X,1HI,2X,1HJ,7X,1HX,10X,1HY,10X,1HM,10X,2HM*,7X,
1 SHTHETA,8X,1HT,8X,1HP,8X,1HV,5X,7HDENSITY,3X,9HTOLERANCE,2X,
2 9HITERATION,2X,5HERROR/12X,5H(IN.),6X,5H(IN.),28X,5H(DEG),5X,
3 7H(DEG R),2X,6H(PSIA),2X,8H(FT/SEC),1X,10H(LB/CU-FT),21X,
4 9HINDICATOR//)

811 WRITE (6,670) II,JI,XN,YN,FMN,FMSN,THETAN,TN,PN,VN,RHUN,DELTA,
1 ICOUNT,KTEST

    THETAN = THETAN * PI / 180.

20 CONTINUE

670 FORMAT (1X,2I3,F12.7,BF11.7,F12.7,F9.1,F8.2,F9.1,F11.6,F11.7,
1 I7,8X,1I)

```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
IF (I - (I/2)*2) 59, 59, 2100
2100 K = 0
GO TO 2009
59 GO TO (731,313), KCHECK
731 IF (FMSFLD(1,JEND+1)) 313, 313, 55
55 IF (XL - XNLTH) 323, 313, 313
323 CALL CASE3(XL,YL,FML,FHETAL,FMSTAR,FMVEC,XN,YN,FMSN,THETAN,NTABLE,
1 DELTA,ICASE,ICOUNT,KTEST)
1F (KTEST) 2003, 2003, 313
313 FMN = 0.
FMSN = 0.
PN = 0.
TN = 0.
VN = 0.
RHUN = 0.
GO TO 307
2003 CALL PROPTY(FMSN,P,T,FMW,GAMMA,FMVEC,FMSTAR,NTABLE,PN,TN,VN,
1 RHUN,FMN)
      WRITE (2,552) XL, YL, XN, YN
      X = YEXIT * SQRT(FMN*FMN-1.) + XN
      IF (X - ANL *XNLTH) 307, 732, 732
732 KCHECK = 2
307 XFIELD(2,NSONE) = XN
YFIELD(2,NSONE) = YN
FMSFLD(2,NSONE) = FMSN
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
THETAV(2,NSONE) = THETAN
K = 1
I1 = I + 1
IF (FMSFLD(1,JEND+1)) 2009, 2009, 2008
2008 IF (XL - XNLTH) 2222, 2009, 2009.
2222 NPRINT = NPRINT + 1
THETAN = THETAN * 180. / PI
IF (NPRINT - 52) 821, 821, 822
822 NDEL = NPRINT - 53 - 56*((NPRINT-52)/56)
IF (NDEL) 821, 823, 821
823 WRITE (6,686)
821 WRITE (6,670) I1,NSONE,XN,YN,FMN,FMSN,THETAN,TN,PN,VN,RHUN,DELTA,
1 ICOUNT,KTEST
THETAN = THETAN * PI / 180.
2009 I = I + 1
CALL STREAM(XFIELD,YFIELD,FMSFLD,THETAV,K,NSONE,XSTR,YSTR,THSTR,
1 NTOTAL)
DO 2004 J = 1, NSONE
XFIELD(1,J) = XFIELD(2,J)
YFIELD(1,J) = YFIELD(2,J)
FMSFLD(1,J) = FMSFLD(2,J)
THETAV(1,J) = THETAV(2,J)
2004 FMSFLD(2,J) = 0.
IF (I - (I/2)*2) 25, 25, 44
25 IF (FMSFLD(1,1)) 40, 40, 4000
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
4000 XL = XFIELD(1,1)
      YL = YFIELD(1,1)
      FMSL = FMSFLD(1,1)
      FML = PLTN(FMSL,FMVEC,FMSTAR,NTABLE)
      THETAL = THETAV(1,1)
      CALL CASE4(XL,YL,FML,THETAL,NCT,FMSTAR,FMVEC,XWALL,YWALL,RT,
1 NTABLE,RNX1,XN1,RNX2,XN2,RPX1,XP1,RPX2,XP2,RPX3,XP3,N,XN,YN,
2 FMSN,THETAN,DELTA,ICASE,ICOUNT,KTEST)
      IF (KTEST) 1003, 1003, 310
310 FMN = 0.
      FMSN = 0.
      PN = 0.
      TN = 0.
      VN = 0.
      RHUN = 0.
      GO TO 309
1003 CALL PROPY(FMSN,P,T,FMW,GAMMA,FMVEC,FMSTAR,NTABLE,PN,TN,VN,
1 RHUN,FMN)
      WRITE (2,552) XL, YL, XN, YN
      JLAST = JLAST + 1
      XCWALL(JLAST) = XN
      YCWALL(JLAST) = YN
      FMWALL(JLAST) = PLTN(FMSN,FMVEC,FMSTAR,NTABLE)
      PWALL(JLAST) = PLTN(FMSN,P,FMSTAR,NTABLE)
309 XFIELD(2,1) = XN
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

```
YFIELD(2,1) = YN
FMSFLD(2,1) = FMSN
THETAV(2,1) = THETAN
I1 = I + 1
J1 = 1
NPRINT = NPRINT + 1
THETAN = THETAN * 180. / PI
IF (NPRINT - 52) 831, 831, 832
832 NDEL = NPRINT - 53 - 56*((NPRINT-52)/56)
IF (NDEL) 831, 833, 831
833 WRITE (6,686)
831 WRITE (6,670) I1,J1,XN,YN,FMN,FMSN,THETAN,TN,PN,VN,RHUN,DELTA,
1 ICOUNT,KTEST
THETAN = THETAN * PI / 180.
JEND = NSONE - 2
IF (XN - XNLTH) 45, 40, 40
40 XCWALL(1) = XSAUER(1)
YCWALL(1) = YSAUER(1)
FMWALL(1) = FMSAUR(1)
PWALL(1) = PLTN(FMWALL(1),P,FMVEC,NTABLE)
CALL PERFOR(XSAUER,YSAUER,FMSAUR,THETAS,XCWALL,YCWALL,PWALL,
1 P,T,GAMMA,FMW,FMVEC,NTABLE,NSONE,JLAST,N,PA,PC,RT,XNLTH,YEXIT)
C
C      WRITE ALL INFORMATION ABOUT FIELD POINTS AND STREAMLINES ON
C      TAPE 2 TO FEED THE SC-4020 PLOTTER
```

FORTRAN IV PROGRAM LISTING OF SP-37 MAIN PROGRAM

C

```
      WRITE (2,552) XN, YN, XN, YN
      WRITE (2,276) JLAST, (XCWALL(J), YCWALL(J), J = 1, JLAST)
      WRITE (2,553) NTOTAL
      REWIND 1
      NPOINT = 0
244 READ (1) XL, YL, XR, YR
      WRITE (2,552) XL, YL, XR, YR
      NPOINT = NPOINT + 1
      IF (NPOINT - NTOTAL) 244, 245, 245
245 CONTINUE
      WRITE (6,622)
622 FORMAT (//////25X,25H***** END OF CASE *****)
      IF (NCASE - NDATA) 751, 752, 752
751 NCASE = NCASE + 1
      GO TO 93
752 CONTINUE
      REWIND 2
      PAUSE 77777
      CALL EXIT
      END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE1

C
C
C
C

SUBROUTINE TO CALCULATE A NEW FIELD POINT WITH BOTH INPUT POINTS
LOCATED IN THE CENTER FIELD

SUBROUTINE CASE1(XXR,YYR,FFMR,THETAP,XXL,YYL,FFML,THETAQ,FMSTAR,
1 FMVEC,NTABLE,XN,YN,FMSN,THETAN,DELTA,ICASE,ICOUNT,KTEST)
DIMENSION FMVEC(80), FMSTAR(80)
TAN(X) = SIN(X)/COS(X)
ICASE = 1
ICOUNT = 0
KTEST = 0
XR = XXR
YR = YYR
FMR = FFMR
THETAR = THETAP
XL = XXL
YL = YYL
FML = FFML
THETAL = THETAQ
FMSL = PLTN(FML,FMSTAR,FMVEC,NTABLE)
FMSR = PLTN(FMR,FMSTAR,FMVEC,NTABLE)
IF (FML - 1.0) 101, 101, 102
102 IF (FMR - 1.0) 101, 101, 103
101 WRITE (6,666) XR, YR, FMR, XL, YL, FML
666 FORMAT (1H1,10X,46ERROR MESSAGE, EITHER FMR OR FML IS LESS THAN

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE1

```

1 3HUNE//1IX,6F12.7)

GO TO 800

103 ALPHAL = ATAN(SQRT(1./(FML*FML-1.)))
ALPHAR = ATAN(SQRT(1./(FMR*FMR-1.)))
FLAMDL = TAN(THETAL+ALPHAL)
FLAMDR = TAN(THETAR-ALPHAR)
HL = 1./(TAN(ALPHAL)*FMSL)
HR = 1./(TAN(ALPHAR)*FMSR)
BETAL = SIN(THETAL)*SIN(ALPHAL)/(YL*SIN(THETAL+ALPHAL))
BETAR = SIN(THETAR)*SIN(ALPHAR)/(YR*COS(THETAR-ALPHAR))
XN=((FLAMDR*XR-FLAMDL*XL)+YL-YR)/(FLAMDR-FLAMDL)
YN = YL - FLAMDL*(XL-XN)
FMSN = (THETAR-THETAL+HL*FMSL+HR*FMSR-BETAR*(XR-XN)-BETAL*(YL-YN
1 ))/(HL+HR)
IF (FMSN - 1.) 31, 31, 32
31 IF (FMSR - FMSL) 91, 91, 92
91 FMSN = FMSL
THETAN = THETAL
GO TO 30
92 FMSN = FMSR
THETAN = THETAR
GO TO 30
32 THETAN = THETAL-HL*(FMSL-FMSN)+BETAL*(YL-YN)
30 FMN = PLTN(FMSN,FMVEC,FMSTAR,NTABLE)
IF (FMSN - FMSTAR(NTABLE)) 105, 105, 104

```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE1

```

104 KTEST = 1
      RETURN
105 ALPHAN = ATAN(SQRT(1./(FMN*FMN-1.)))
      FLAMN = TAN(THETAN+ALPHAN)
      FLAMNP= TAN(THETAN-ALPHAN)
      HN = 1./(TAN(ALPHAN)*FMSN)
      BETAN = SIN(THETAN)*SIN(ALPHAN)/(YN*SIN(THETAN+ALPHAN))
      BETANP= SIN(THETAN)*SIN(ALPHAN)/(YN*COS(THETAN-ALPHAN))
      FLAMRN = (FLAMDR + FLAMNP)/2.
      FLAMLN = (FLAMDL + FLAMN)/2.
      HLN = (HL + HN)/2.
      HRN = (HR + HN)/2.
      BETARN = (BETAR + BETANP)/2.
      BETALN = (BETAL + BETAN)/2.
      XN = ((FLAMRN*XR-FLAMLN*XL)+YL-YR)/(FLAMRN-FLAMLN)
      YN = YL - FLAMLN*(XL-XN)
      FMSN = (THETAR-THEtal+HLN*FMSL+HRN*FMSR-BETARN*(XR-XN)-BETALN*
1 (YL-YN))/(HLN+HRN)
      THETA = THEtal-HLN*(FMSL-FMSN)+BETALN*(YL-YN)
      DELTA = THETA - THETAN
      IF (ABS (DELTA) - 1.E-07) 10, 10, 20
20 IF (ICOUNT - 50) 40, 10, 10
40 ICOUNT = ICOUNT + 1
      THETAN = THETA
      GO TO 30

```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE1

10 THETAN = THETA

RETURN

800 CALL DUMP

END

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE2

C
C
C
C

SUBROUTINE TO CALCULATE A NEW FIELD POINT WITH ONE OF THE INPUT
POINTS ON THE AXIS OF SYMMETRY

```
SUBROUTINE CASE2(XXR,YYR,FFMR,THETAP,XXL,YYL,FFML,THETAQ,FMSTAR,  
1 FMVEC,NTABLE,XN,YN,FMSN,THETAN,DELTA,ICASE,ICOUNT,KTEST)  
DIMENSION FMVEC(80), FMSTAR(80)  
TAN(X) = SIN(X)/COS(X)  
ICASE = 2  
ICOUNT = 0  
KTEST = 0  
XR = XXR  
YR = YYR  
FMR = FFMR  
THETAR = THETAP  
XL = XXL  
YL = YYL  
FML = FFML  
THETAL = THETAQ  
FMSL = PLTN(FML,FMSTAR,FMVEC,NTABLE)  
FMSR = PLTN(FMR,FMSTAR,FMVEC,NTABLE)  
IF (FML - 1.0) 101, 101, 102  
102 IF (FMR - 1.0) 101, 101, 103  
101 WRITE (6,666) XR, YR, FMR, XL, YL, FML  
666 FORMAT (1H1,10X,46HERROR MESSAGE, EITHER FMR OR FML IS LESS THAN
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE2

```
1 3H0NE//11X,6F12.7)
GO TO 800
103 ALPHAL = ATAN(SQRT(1./(FML*FML-1.)))
ALPHAR = ATAN(SQRT(1./(FMR*FMR-1.)))
FLAMDL = TAN(THETAL+ALPHAL)
FLAMDR = TAN(THETAR-ALPHAR)
BETAR = SIN (THETAR)*SIN (ALPHAR)/(YR*COS (THETAR-ALPHAR))
HL = 1./(TAN(ALPHAL)*FMSL)
HR = 1./(TAN(ALPHAR)*FMSR)
XN = (YR+FLAMDL*XL-FLAMDR*XR)/(FLAMDL-FLAMDR)
YN = FLAMDL*(XN-XL)
FMSN = (2.*THETAR+HL*FMSL+2.*HR*FMSR+2.*BETAR*(XN-XR))/(HL+2.*HR)
IF (FMSN - 1.) 31, 31, 32
31 IF (FMSR - FMSL) 91, 91, 92
91 FMSN = FMSL
THETAN = THETAL
GO TO 30
92 FMSN = FMSR
THETAN = THETAR
GO TO 30
32 THETAN = HL*(FMSN-FMSL)/2.
30 FMN = PLTN(FMSN,FMVEC,FMSTAR,NTABLE)
IF (FMSN - FMSTAR(NTABLE)) 105, 105, 104
104 KTEST = 1
RETURN
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE2

```

105 ALPHAN = ATAN(SQRT(1./(FMN*FMN-1.)))

      FLAMN = TAN(THETAN+ALPHAN)

      FLAMNP= TAN(THETAN-ALPHAN)

      HN = 1./(TAN(ALPHAN)*FMSN)

      BETAN = SIN(THETAN)*SIN(ALPHAN)/(YN*SIN(THETAN+ALPHAN))

      BETANP= SIN(THETAN)*SIN(ALPHAN)/(YN*COS(THETAN-ALPHAN))

      FLAMLN = (FLAMDL + FLAMN)/2.

      FLAMRN = (FLAMDR + FLAMNP)/2.

      HLN = (HL + HN)/2.

      HRN = (HR + HN)/2.

      BETALN = (THETAN/YN + BETAN) / 2.

      BETARN = (BETAR + BETANP)/2.

      XN = (YR+FLAMLN*XL-FLAMRN*XR)/(FLAMLN-FLAMRN)

      YN = FLAMLN*(XN-XL)

      FMSN = (THETAR+HLN*FMSL+HRN*FMSR-BETARN*(XR-XN)+BETALN*YN)/
1 (HLN+HRN)

      THETA = HLN*(FMSN-FMSL) - BETALN*YN

      DELTA = THETA - THETAN

      IF (ABS (DELTA) - 1.L-07) 10, 10, 20

20 IF (ICOUNT - 50) 40, 10, 10

40 ICOUNT = ICOUNT + 1

      THETAN = THETA

      GO TO 30

10 THETAN = THETA

      RETURN

```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE2

800 CALL DUMP

END

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE3

C
C
C

SUBROUTINE CASE3(XR,YR,FMR,THETAR,FMSTAR,FMVEC,XN,YN,FMSN,THETAN,
1 NTABLE,DELMN,ICASE,ICOUNT,KTEST)
DIMENSION FMVEC(80), FMSTAR(80)
TAN(X) = SIN(X)/COS(X)
ICASE = 3
ICOUNT = 0
KTEST = 0
YN = 0.
THETAN = 0.
FMSR = PLTN(FMR,FMSTAR,FMVEC,NTABLE)
IF (FMR - 1.0) 101, 101, 102
101 WRITE (6,666) XR, YR, FMR
666 FORMAT (1H1,10X,35HEMORROR MESSAGE, FMR IS LESS THAN ONE//
1 11X,3F12.7)
GO TO 800
102 ALPHAR = ATAN(SQRT(1./(FMR*FMR-1.)))
FLAMDR = TAN(THETAR-ALPHAR)
HR = 1./(TAN(ALPHAR)*FMSR)
BETAR = SIN(THETAR)*SIN(ALPHAR)/(YR*COS(THETAR-ALPHAR))
XN = XR - YR/FLAMDR
FMSN = (THETAR+HR*FMSR+BETAR*(XN-XR))/HR
30 FMN = PLTN(FMSN,FMVEC,FMSTAR,NTABLE)

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE3

```
IF (FMSN = FMSTAR(NTABLE)) 105, 105, 104
104 KTEST = 1
      RETURN
105 ALPHAN = ATAN(SQRT(1./(FMN*FMN-1.)))
      FLAMNP = TAN(THETAN-ALPHAN)
      HN = 1./(TAN(ALPHAN)*FMSN)
      FLAMRN = (FLAMDR + FLAMNP)/2.
      HRN = (HR + HN)/2.
      BETAN = TAN(ALPHAN)*THETAR/YR
      BETARN = (BETAR + BETAN)/2.
      XN = XR - YR/FLAMRN
      FMSNS = (THETAR+HRN*FMSR+BETARN*(XN-XR))/HRN
      DELMN = FMSNS - FMSN
      IF (ABS(DELMN) = 1.E-07) 10, 10, 20
20 IF (ICOUNT = 50) 40, 10, 10
40 ICOUNT = ICOUNT + 1
      FMSN = FMSNS
      GO TO 30
10 FMSN = FMSNS
      RETURN
800 CALL DUMP
      END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE4

C
C
C

SUBROUTINE TO CALCULATE A NEW POINT ON THE NOZZLE CONTOUR

SUBROUTINE CASE4(XL,YL,FML,THETAL,NCT,FMSTAR,FMVEC,XC,YC,RT,
1 NTABLE,RNX1,XN1,RNX2,XN2,RPX1,XP1,RPX2,XP2,RPX3,XP3,N,
2 XN,YN,FMSN,THEtan,DELMN,ICASE,ICOUNT,KTEST)
DIMENSION FMVEC(80), FMSTAR(80), XC(250), YC(250), FMTRIX(8,9)
TAN(X) = SIN(X)/COS(X)
NP1 = N + 1
NP2 = N + 2
ICASE = 4
ICOUNT = 0
KTEST = 0
FMSNT = 50.0
IF (FML - 1.0) 101, 101, 102
101 WRITE (6,666) XL, YL, FML
666 FORMAT (1H1,10X,35HERROR MESSAGE, FML IS LESS THAN ONE//
1 11X,3F12.7)
GO TO 800
102 ALPHAL = ATAN(SQRT(1./(FML*FML-1.)))
BETAL = SIN(THETAL)*SIN(ALPHAL)/(YL*SIN(THETAL+ALPHAL))
FMSL = PLTN(FMI,FMSTAR,FMVEC,NTABLE)
HL = 1./(TAN(ALPHAL)*FMSL)
HLN = HL
BETALN = BETAL

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE4

```
FLAML = TAN(THETAL+ALPHAL)
FLAMLN = FLAML
155 AS = FLAMLN
BS = - 1.
CS = YL - XL*FLAMLN
KR = 1
245 GO TO (205,215,225,235,240), KR
205 RC = RNX1
CXL = XN1
CXR = XN2
GO TO 250
215 RC = RNX2
CXL = XN2
CXR = 0.
GO TO 250
225 RC = RPX1
CXL = 0.
CXR = XP1
GO TO 250
235 RC = RPX2
CXL = XP1
CXR = XP2
GO TO 250
240 RC = RPX3
CXL = XP2
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE4

```

CXR = XP3

250 Y1 = RT + RC

A1 = AS*AS + BS*BS

B1 = 2.* (BS*CS - Y1*AS*AS)

C1 = AS*AS*Y1*Y1 + CS*CS - AS*AS*RC*RC

IF (B1*B1-4.*A1*C1) 255, 10, 15

10 YN = -B1/(2.*A1)

XN = -(BS*YN + CS)/AS

GO TO 270

15 YN = (-B1 - SQRT(B1*B1-4.*A1*C1))/(2.*A1)

XN = -(BS*YN + CS)/AS

270 IF (XN-CXL) 271, 140, 260

260 IF (XN-CXR) 140, 140, 255

255 IF (KR-5) 265, 5, 5

265 KR = KR + 1

GO TO 245

5 NC = NCT -1

DO 30 I = 1, NC

SLOPE = (YC(I+1)-YC(I))/(XC(I+1)-XC(I))

XN = -(BS*YC(I)-SLOPE*BS*XC(I)+CS)/(AS+BS*SLOPE)

IF (XN - XC(I+1)) 35, 40, 30

35 IF (XN - XC(I)) 30, 45, 57

40 XN = XC(I+1)

YN = YC(I+1)

K = 0

```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE4

```
GO TO 50

45 XN = XC(I)
      YN = YC(I)
      K = 0
      GO TO 50

30 CONTINUE
      I = NC
      57 K = 1
      50 CALL POLY(XC,YC,I,N,NCT,FMTRIX)
      IF (K) 198, 198, 73
      73 X = XC(1)

130 KCOUNT = NP1
      YN = FMTRIX(NP1,NP2)
      83 KCOUNT = KCOUNT - 1
      IF (KCOUNT) 81, 81, 82
      82 YN = YN + FMTRIX(KCOUNT,NP2) • X** (NP1-KCOUNT)
      GO TO 83

81 XN = -(BS*YN + LS) / AS
      IF (XN - 1.) 246, 246, 247
      246 DELTAX = XN - X
      GO TO 248

247 DELTAX = (XN - X)/XN
      248 IF (ABS(DELTAX) - 1.E-07) 198, 198, 125
      125 X = XN
      GO TO 130
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE4

```

198 KCOUNT = N
      SLOPE = FMTRIX(N,NP2)
86 KCOUNT = KCOUNT - 1
      IF (KCOUNT) 84, 84, 85
85 SLOPE = SLOPE + FLOAT(NP1-KCOUNT) • FMTRIX(KCOUNT,NP2) *
      1 XN**(N-KCOUNT)
      GO TO 86
84 THETAN = ATAN(SLUPE)
      GO TO 193
140 THETAN = ATAN(XN/(YI-YN))
193 FMSN = (THETAN - THETAL-BETALN*(YL-YN))/HLN+FMSL
      FMN = PLTN(FMSN ,FMVLC,FMSTAR,NTABLE)
      IF (FMSN - FMSTAR(NTABLE)) 105, 105, 104
104 KTEST = 1
      RETURN
105 ALPHAN = ATAN(SQRT(1./(FMN*FMN-1.)))
      FLAMN = TAN(THETAN + ALPHAN)
      HN = 1./(TAN(ALPHAN)*FMSN)
      BETAN = SIN(THETAN)*SIN(ALPHAN)/(YN*SIN(THETAN+ALPHAN))
      FLAMLN = (FLAML+FLAMN)/2.
      HLN = (HL + HN)/2.
      BETALN = (BETAL+BETAN)/2.
      DELMN = FMSN - FMSNT
      IF (ABS (DELMN) - 1.E-07) 160, 160, 150
150 IF (ICOUNT - 50 ) 710, 160, 160

```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE CASE4

```
710 ICOUNT = ICOUNT + 1
      FMSNT = FMSN
      GO TO 155
160 RETURN
271 WRITE (6,698)
698 FORMAT (1H1,10X,43HTHE X-COORDINATE OF THE INPUT POINT IS TOO ,
1 18HSMALL---DATA ERROR)
800 CALL DUMP
END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE THERMO

C
C

SUBROUTINE FOR CALCULATING THERMODYNAMIC DATA FOR FROZEN FLOW

C

SUBROUTINE THERMU(NTABLE,G,W,PC,TC,P,T,FMW,GAMMA,FMVEC,FMSTAR,
1 CSTAR)

DIMENSION P(80), T(80), FMVEC(80), FMSTAR(80), FMW(80), GAMMA(80)

DELM = 0.1

DO 92 I = 1, NTABLE

FI = I

FMVEC(I) = 1.0 + DELM * (FI-1.)

FMSTAR(I) = SQRT(0.5*(G+1.)*FMVEC(I)*FMVEC(I)/(1.+0.5*(G-1.)*
1 FMVEC(I)*FMVEC(I)))

T(I) = TC / (1.+0.5*(G-1.)*FMVEC(I)*FMVEC(I))

P(I) = PC / (1.+0.5*(G-1.)*FMVEC(I)*FMVEC(I))**(G/(G-1.))

GAMMA(I) = G

FMW(I) = W

92 CONTINUE

CSTAR = SQRT(32.174*1546.336*G*T(1)/W)

RETURN

END

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PLTN

C
C SUBROUTINE TO PERFORM LINEAR INTERPOLATION BETWEEN THERMODYNAMIC
C DATA
C
FUNCTION PLTN(FM,FM1,FM2,NTABLE)
DIMENSION FM1(80), FM2(80)
IF (FM2(1)-FM2(NTABLE)) 230, 230, 235
235 DO 240 I = 1, NTABLE
IF (FM2(I) - FM) 35, 30, 240
240 CONTINUE
I = NTABLE
50 WRITE (6,600)
600 FORMAT (1H1,5X,44HVALUE BEYOND TABLE LIMITS, EXTRAPOLATION WAS,
1 10H PERFORMED//)
X = FM
WRITE (6,601) X
601 FORMAT (20X,2F12.7)
DO 70 J = 1, NTABLE
X = FM1(J)
Y = FM2(J)
WRITE (6,601) X, Y
70 CONTINUE
GO TO 30
230 DO 10 I = 1, NTABLE
IF (FM2(I) - FM) 10, 30, 35

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PLTN

```
10 CONTINUE
I = NTABLE
GO TO 50
35 IF (I - 1) 45, 45, 30
45 I = 2      .
GO TO 50
30 PLTN = (FM1(I)-FM1(I-1))*(FM-FM2(I-1))/(FM2(I)-FM2(I-1))+FM1(I-1)
40 RETURN
END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE OPTIMS

C
C SUBROUTINE FOR CALCULATING THE STARTING LINE BY HALLS THEORY
C
SUBROUTINE OPTIMS(SIGMA,R,FMVEC,FMSTAR,GAMMA,NTABLE,XP3,XMACH,RT,
1 NSUNE,XSAUER,YSAUER,THETAS)
DIMENSION FMVEC(80), FMSTAR(80), GAMMA(80), XSAUER(60),YSAUER(60),
1 THETAS(60)
FIRSTF(A,B,C) = (A*B+C)/C
SECONF (A,B,C,D) = (A*B*C+B*C*D)/D
R = R / RT
XP3 = XP3 / RT
XL = 0.
XR = XP3
ITEST = 0
70 XSAUER(1) = (XL + XR)/2.
YSAUER(1)= 1.+0.5*XSAUER(1)*XSAUER(1)/R+0.125*SIGMA*XSAUER(1)*
1 XSAUER(1)*XSAUER(1)*XSAUER(1)/(R*R*R)
X = XSAUER(1)
Y = YSAUER(1)
ICOUNT = 0
G=GAMMA(2)
5 A1=FIRSTF(2., 9.,24.)
A2=FIRSTF(4.,15.,24.)
A3=FIRSTF(10.,57.,288.)
A4 = FIRSTF(2.,-3.,6.)

FORTRAN IV PROGRAM LISTING OF SUBROUTINE OPTIMS

```
A5=SECONF(556.,1899.,3231.,10368.)  
A6=SECONF(388.,1233.,1953.,2304.)  
A7=SECONF(304.,858.,1269.,1728.)  
A8=SECONF(2708.,7839.,14211.,82944.)  
A9=SECONF(52.,99.,375.,384.)  
A10=SECONF(52.,99.,303.,192.)  
A11=SECONF(200.,72.,639.,1152.)  
A12 = FIRSTF(5.,-5.,8.)  
A13 = FIRSTF(13.,-27.,48.)  
A14 = SECONF(4.,-57.,27.,144.)  
B1=FIRSTF(8.,15.,72.)  
B2=FIRSTF(20.,45.,96.)  
B3=FIRSTF(28.,75.,288.)  
B4=FIRSTF(4.,9.,12.)  
B5 = SECONF(6836.,16695.,14211.,82944.)  
B6=SECONF(3380.,8703.,7875.,13824.)  
B7=SECONF(3748.,8859.,8964.,13824.)  
B8=SECONF(9044.,17631.,20745.,82944.)  
B9=SECONF(556.,1113.,981.,1728.)  
B10=SECONF(388.,801.,693.,576.)  
B11=SECONF(304.,645.,549.,864.)  
B12 = SECONF(52.,3.,-33.,192.)  
B13 = SECONF(52.,27.,-9.,192.)  
B14=FIRSTF(1.,1.,4.)  
Z = X/SQRT((G+1.)/(2.*R))
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE OPTIMS

```

Q1 = 0.5*Y*Y - 0.25 + Z

Q2 = A1*Y*Y*Y*Y - A2*Y*Y + A3 + Z*(Y*Y-0.625)-A4*Z*Z

Q3 = A5*Y*Y*Y*Y*Y*Y - A6*Y*Y*Y*Y + A7*Y*Y - A8 + Z*(A9*Y*Y*Y*Y-
1 A10*Y*Y+A11) + Z*Z*(-A12*Y*Y+A13) + A14*Z*Z*Z

QBAR = 1. + Q1/R + Q2/(R*R) + Q3/(R*R*R)

GBAR=PLTN(QBAR,GAMMA,FMSTAR,NTABLE)

DELG = GBAR - G

IF (ABS (DELG) - 1.E-05) 30, 30, 36

36 IF (ICOUNT - 20) 35, 30, 30

35 ICOUNT = ICOUNT + 1

G = (G + GBAR)/2.

GO TO 5

30 XMACH = PLTN(QBAR,FMVEC,FMS1AR,NTABLE)

ALPHA = ATAN (1./SQRT (XMACH*XMACH-1.))

THETAS(1) = ATAN(XSAUER(1)/R+0.5*SIGMA*XSAUER(1)*XSAUER(1)*
1 XSAUER(1)/(R*R*R))

BQ=(QBAR-1.)*R

GO = BQ - 0.5*Y*Y + 0.25

DGODY = -Y

DG1DY = 2.*A2*Y - 4.*A1*Y*Y*Y + 2.*A4*GO*DODY - 2.*GO*Y -
1 DGODY*Y*Y + 5.*DGODY/8.

DG2DY = -6.*A5*Y*Y*Y*Y*Y + 4.*A6*Y*Y*Y - 2.*A7*Y - A9*Y**4*DODY -
1 4.*A9*GO*Y*Y*Y + A10*DODY*Y*Y + 2.*A10*GO*Y - A11*DODY +
2 2.*A12*GO*DODY*Y*Y + 2.*A12*GO*GO*Y - 2.*A13*GO*DODY -
3 3.*A14*GO*GO*DODY

```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE OPTIMS

```
DZDY = DGODY + DG1DY/R + DG2DY/R**2
DYDX = 1./(SQRT ((GBAR+1.)/(2.*R))*DZDY)
DELTA = ATAN (ABS (DYDX))
TOLER = DELTA - ABS(THETAS(1) - ALPHA)
IF (TOLER - 3.E-02) 46, 46, 50
50 IF (TOLER - 5.E-02) 55, 55, 60
60 IF (ITEST - 20) 65, 55, 55
46 IF (ITEST - 20) 45, 55, 55
45 ITEST = ITEST + 1
XL = XSAUER(1)
GO TO 70
65 ITEST = ITEST + 1
XR = XSAUER(1)
GO TO 70
55 FNSONE = NSONE
DO 75 I = 2, NSONE
FI = I
YSAUER(I) = YSAUER(I) * (1.-(FI-1.)/(FNSONE-1.))
Y = YSAUER(I)
GO = BQ - 0.5*Y*Y + 0.25
G1 = A2 *Y*Y - A1*Y*Y*Y*Y - A3 + GO*(GO*A4-(Y*Y-0.625))
G2 = -A5*Y*Y*Y*Y*Y + A6*Y*Y*Y*Y - A7*Y*Y + A8 - GO*((A9*
1 Y*Y*Y*Y - A10*Y*Y + A11) + GO*(-A12*Y*Y + A13) + GO*GO*A14)
Z = BQ - 0.5*Y*Y + 0.25 + G1/R + G2/(R*R)
XSAUER(I) = Z * SQRT(0.5*(GBAR+1.)/R)
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE OPTIMS

```
THETA1 = 0.25*Y*Y*Y - 0.25*Y + Y*Z  
THETA2 = B1*Y*Y*Y*Y*Y - B2*Y*Y*Y + B3*Y + B4*Z*(Y*Y*Y-Y)  
THETA3 = B5*Y*Y*Y*Y*Y*Y*Y - B6*Y*Y*Y*Y*Y + B7*Y*Y*Y-B8*Y  
1 + Z*(B9*Y*Y*Y*Y*Y - B10*Y*Y*Y + B11*Y) + Z*Z*(B12*Y*Y*Y - B13*Y)  
2 - B14*Y*Z*Z*Z  
THETAS(I) = SQRT(0.5*(GBAR+1.)/R)*(THETA1/R + THETA2/(R*R) +  
1 THETA3/(R*R*R))  
75 CONTINUE  
DO 78 I = 1, NSONE  
XSAUER(I) = XSAUER(I) * RT  
YSAUER(I) = YSAUER(I) * RT  
78 CONTINUE  
R = R * RT  
XP3 = XP3 * RT  
RETURN  
END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE STREAM

C
C SUBROUTINE FOR CALCULATING STREAM LINES TO FEED INTO SC-4020
C PLOTTER
C
SUBROUTINE STREAM(XFIELD,YFIELD,FMSFLD,THETAV,K,NSONE,XSTR,YSTR,
1 THSTR,NTOTAL)
DIMENSION XFIELD(2,60), YFIELD(2,60), THETAV(2,60), XSTR(60),
1 YSTR(60), THSTR(60), FMSFLD(2,60)
TAN (X) = SIN (X)/COS (X)
YTEST = 10. • YFIELD(2,1)
JSTART = 1
NMONE = NSONE - 1
KI = -1
DO 5 J = 2, NMONE
IF (XSTR(J) + YSTR(J) + THSTR(J)) 29, 28, 29
29 IF (K) 10, 10, 15
10 N = NMONE - 1
IF (KI) 20, 25, 45
20 YNEW = YSTR(J) + TAN (THSTR(J))*(XFIELD(2,1)-XSTR(J))
IF (YNEW - YFIELD(2,1)) 30, 30, 35
35 X1 = XSTR(J)
Y1 = YSTR(J)
X2 = XFIELD(2,1)
WRITE (1) X1, Y1, X2, YNEW
NTOTAL = NTOTAL + 1

FORTRAN IV PROGRAM LISTING OF SUBROUTINE STREAM

```
XSTR(J) = XFIELD(2,1)
YSTR(J) = YNEW
THSTR(J) = THETAV(2,1)
YTEST = YNEW
GO TO 5
30 KI = 0
GO TO 25
15 N = NMONE
25 DO 50 J1 = JSTART, N
    IF (FMSFLD(2,J1+1)) 28, 28, 7
    7 XNEW = ((YSTR(J)-YFIELD(2,J1)-XSTR(J)*TAN (THSTR(J)))*
               1 (XFIELD(2,J1+1)-XFIELD(2,J1))+XFIELD(2,J1)*(YFIELD(2,J1+1)-
               2 YFIELD(2,J1)))/(YFIELD(2,J1+1)-YFIELD(2,J1)-TAN(THSTR(J))*  
               3 (XFIELD(2,J1+1)-XFIELD(2,J1)))
    YNEW = YSTR(J) + TAN (THSTR(J))*(XNEW-XSTR(J))
    IF (YNEW - YFIELD(2,J1)) 8, 9, 19
    8 IF (YNEW - YFIELD(2,J1+1)) 50, 9, 9
    9 IF (YNEW - YTEST) 16, 19, 19
16 X1 = XSTR(J)
    Y1 = YSTR(J)
    WRITE (1) X1, Y1, XNEW, YNEW
    NTOTAL = NTOTAL + 1
    XSTR(J) = XNEW
    YSTR(J) = YNEW
    YTEST = YNEW
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE STREAM

```
THSTR(J) = THETAV(2,J1+1) + (THETAV(2,J1)-THETAV(2,J1+1))*(YNEW-
1 YFIELD(2,J1+1))/(YFIELD(2,J1)-YFIELD(2,J1+1))
GO TO 12
50 CONTINUE
K1 = 1
IF (K) 45, 45, 51
12 JSTART = J1
GO TO 5
45 YNEW = YSTR(J) + TAN (THSTR(J))*(XFIELD(2,N+1)-XSTR(J))
IF (YNEW) 46, 47, 48
48 X1 = XSTR(J)
Y1 = YSTR(J)
X2 = XFIELD(2,N+1)
WRITE (1) X1, Y1, X2, YNEW
NTOTAL = NTOTAL + 1
XSTR(J) = XFIELD(2,N+1)
YSTR(J) = YNEW
THSTR(J) = THETAV(2,N+1)
YTEST = YNEW
5 CONTINUE
RETURN
19 WRITE (6,603)
603 FORMAT (1H1,10X,22HSTREAMLINES CROSS OVER)
28 DO 21 I = J, NMUNE
XSTR(I) = 0.
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE STREAM

```
YSTR(I) = 0.  
21 THSTR(I) = 0.  
      RETURN  
46 WRITE(6,601)  
601 FORMAT (1H1,10X,36HSTREAM LINE CROSSES AXIS OF SYMMETRY)  
      RETURN  
47 WRITE(6,602)  
602 FORMAT (1H1,10X,20HSTREAM LINES OVERLAP)  
51 RETURN  
      END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE POLY

C
C SUBROUTINE TO FIT AN NTH ORDER POLYNOMIAL. N = 1 TO 7
C
SUBROUTINE POLY(XC,YC,L,N,NCT,FMTRIX)
DIMENSION XC(250), YC(250), FMTRIX(8,9)
NP1 = N + 1
NP2 = N + 2
IF (L - N/2) 33, 33, 60
33 NI = 1
GO TO 145
60 IF (L - NCT + (N-1)/2) 66, 65, 65
66 NI = L - N/2
GO TO 145
65 NI = NCT - N
145 DO 100 I = 1, NP1
DO 105 J = 1, N
NI=NI
105 FMTRIX(I,J) = XC(NI)**(NP1-J)
FMTRIX(I,NP1) = 1.
FMTRIX(I,NP2) = YC(NI)
100 NI = NI + 1
DO 5 I = 1, N
IF (FMTRIX(I,I)) 5, 10, 5
5 CONTINUE
GO TO 15

FORTRAN IV PROGRAM LISTING OF SUBROUTINE POLY

```
10 DO 20 J = 1, NP2
      TEMP = FMTRIX(I,J)
      FMTRIX(I,J) = FMTRIX(NP1,J)
      FMTRIX(NP1,J) = TEMP
20 CONTINUE
15 DO 110 K = 1, NP1
      K1 = K + 1
      DO 115 J = K1, NP2
115 FMTRIX(K,J) = FMTRIX(K,J)/FMTRIX(K,K)
      FMTRIX(K,K) = 1.
      DO 110 I = 1, NP1
      IF (I - K) 130, 110, 130
130 DO 120 J = K1, NP2
120 FMTRIX(I,J) = FMTRIX(I,J)-FMTRIX(I,K)*FMTRIX(K,J)
      FMTRIX(I,K) = 0.
110 CONTINUE
      RETURN
      END
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PROPTY

C

C SUBROUTINE TO CALCULATE DIFFERENT THERMODYNAMIC PROPERTIES

C

SUBROUTINE PROPTY(FMSN,P,T,FMW,GAMMA,FMVEC,FMSTAR,NTABLE,PN,TN,

1 VN,RHUN,FMN)

DIMENSION P(80), T(80), FMW(80), GAMMA(80), FMVEC(80), FMSTAR(80)

PN = PLTN(FMSN,P,FMSTAR,NTABLE)

TN = PLTN(FMSN,I,FMSTAR,NTABLE)

FMN = PLTN(FMSN,FMVEC,FMSTAR,NTABLE)

GN = PLTN(FMSN,GAMMA,FMSTAR,NTABLE)

FMWN = PLTN(FMSN,FMW,FMSTAR,NTABLE)

CN = SQRT(32.174*1546.336*GN*TN/FMWN)

VN = CN * FMN

RHUN = 144.0 * PN * FMWN / (1546.336 + TN)

RETURN

END

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PERFOR

C
C
C
C

SUBROUTINE FOR CALCULATING NOZZLE PERFORMANCE BY INTEGRATING
ALONG STARTING LINE AND NOZZLE CONTOUR

SUBROUTINE PERFOR(XSAUER, YSAUER, FMSAUR, THETAS, XWALL, YWALL, PWALL,
1 P, T, GAMMA, FMW, FMVEC, NTABLE, NSONE, JLAST, N, PA, PC, RT, XNLTH, YEXIT)
DIMENSION XSAUER(60), YSAUER(60), THETAS(60), FMSAUR(60),
1 XWALL(250), YWALL(250), PWALL(250), P(80), T(80), FMW(80),
2 GAMMA(80), FMVEC(80), FMTRIX(8,9), PUSHSW(250)
PI = 3.1415926536
NP2 = N + 2
NSMONE = NSONE - 1
FLOW = 0.
PUSH = 0.
DO 5 I = 1, NSMUNE
THETAV = (THETAS(I)+THETAS(I+1))/2.
THETAN = ATAN ((XSAUER(I)-XSAUER(I+1))/(YSAUER(I+1)-YSAUER(I)))
THETAT = THETAN - THETAV
P1 = PLTN(FMSAUR(I), P, FMVEC, NTABLE)
P2 = PLTN(FMSAUR(I+1), P, FMVEC, NTABLE)
PS = (P1 + P2)/2.
T1 = PLTN(P1, T, P, NTABLE)
T2 = PLTN(P2, T, P, NTABLE)
TS = (T1 + T2)/2.
G1 = PLTN(P1, GAMMA, P, NTABLE)

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PERFOR

```
G2 = PLTN(P2,GAMMA,P,NTABLE)
GS = (G1 + G2)/2.
FMW1 = PLTN(P1,FMW,P,NTABLE)
FMW2 = PLTN(P2,FMW,P,NTABLE)
FMWS = (FMW1 + FMW2)/2.
CS = SQRT (32.174*GS*1546.336*TS/FMWS)
VS = CS * (FMSAUR(I)+FMSAUR(I+1))/2.
RHU = 144.0 * PS * FMWS /(1546.336 * TS)
DA = PI * (YSAUER(I+1)**2 - YSAUER(I)**2) / COS(THETAN)
DA = ABS(DA)
VN = VS * COS(THETAT)
FLOW = FLOW + DA*RHU*VN / 144.0
PUSH = PUSH + DA*(PS*COS(THETAN) + RHU*VN*VS*COS(THETAV) /
1 (144.0*32.174))
5 CONTINUE
PUSH = ABS(PUSH)
FLOW = ABS(FLOW)
PULSE = 0.
DO 104 J = 2, JLAST
I = J - 1
CALL POLY(YWALL,PWALL,I,N,JLAST,FMTRIX)
KCOUNT = NP2
130 KCOUNT = KCOUNT - 1
POWER = NP2 - KCOUNT + 1
IF (KCOUNT) 112, 112, 132
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PERFOR

```
132 PULSE = PULSE + FMTRIX(KCOUNT,NP2) • (YWALL(J)**POWER -  
1 YWALL(J-1)**POWER) / POWER  
GO TO 130  
112 PUSHSW(J) = 2.*PI*PULSE + PUSH - PA*PI*YWALL(J)*YWALL(J)  
104 CONTINUE  
IF (XWALL(JLAST)-XNLTH) 116, 116, 117  
117 PUSHSW(JLAST) = PUSHSW(JLAST-1) + (PUSHSW(JLAST)-PUSHSW(JLAST-1))  
1 *(XNLTH-XWALL(JLAST-1))/(XWALL(JLAST)-XWALL(JLAST-1))  
XWALL(JLAST) = XNLTH  
YWALL(JLAST) = YEXIT  
116 WRITE (6,641) .  
641 FORMAT (1H1,10X,47HPERFORMANCE BY INTEGRATING ALONG NOZZLE CONTOUR  
1 15H AT WALL POINTS//19X,1HX,12X,1HY,12X,6HTHRUST,7X,  
2 11HSP. IMPULSE,9X,2HCF/17X,5H(IN.),8X,5H(IN.),10X,6H(LBF.),6X,  
3 13H(LBF-SEC/LBM)//)  
DO 151 J = NSONE, JLAST  
SPIPLS = PUSHSW(J) / FLOW  
CF = PUSHSW(J)/(PC*PI*RT*RT)  
X = XWALL(J)  
Y = YWALL(J)  
PUSH = PUSHSW(J)  
151 WRITE (6,642) X, Y, PUSH, SPIPLS, CF  
642 FORMAT (1H0,10X,2F13.7,F18.7,2F14.7)  
WRITE (6,636) FLOW  
636 FORMAT (//1H0,10X,39HMASS FLOW RATE BY INTEGRATING ALONG THE
```

FORTRAN IV PROGRAM LISTING OF SUBROUTINE PERFOR

1 14H STARTING LINE//12X,11HFLOW RATE =,F13.7,8H LBM/SEC)

RETURN

END

FORTRAN II PROGRAM LISTING OF SP-37 PLOTTER PROGRAM

C
C AN IBM 7090 PROGRAM WHICH READS INFORMATION OBTAINED FROM THE
C AXI-SYMMETRIC, SUPERSONIC NOZZLE FLOW PROGRAM, TRANSFORMS AND
C WRITES THESE INFORMATION ON FORTRAN TAPE 16 TO FEED THE SC-4020
C PLOTTER TO OBTAIN MICROFILM PLOTS OF FLOW FIELD AND STREAMLINES
C OF THE ABOVE DESCRIBED NOZZLE

C

DIMENSION XPLOT(250), YPLOT(250), BCDX(12), BCDY(12), XSAUER(60),
1 YSAUER(60)
PRINT 600
600 FORMAT (1H1,10X,47HDESCRIBE IN THIS FIELD YOUR INPUT TAPE REEL NO.
1 51H AND TAPE UNIT ON WHICH THE FORMER IS TO BE MOUNTED/11X,
2 44HAS PART OF YOUR INSTRUCTIONS TO THE OPERATOR)
PAUSE 777
REWIND 3
READ INPUT TAPE 3, 300, NDATA
300 FORMAT (I5)
NCASE = 1
35 READ INPUT TAPE 3, 301, ISYM, XCL, XCR, YCB, YCT
301 FORMAT (I10,4F10.5)
READ INPUT TAPE 3, 303, NPLOT, (XSAUER(J),YSAUER(J),J=1,NPLOT)
303 FORMAT (I10/(12F10.6))
L = -1
CALL LABEL(BCDX,25HX-AXIS (AXIS OF SYMMETRY))
CALL LABEL(BCDY,6HY-AXIS)

FORTRAN II PROGRAM LISTING OF SP-37 PLOTTER PROGRAM

```
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XSAUER,YSAUER)
L = 0
NPLOT = 2
20 READ INPUT TAPE 3, 304, (XPLOT(J), YPLOT(J), J = 1, NPLOT)
304 FORMAT (6F10.7)
IF (XPLOT(1) - XPLOT(2)) 5, 10, 5
10 IF (YPLOT(1) - YPLOT(2)) 5, 15, 5
5 CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XPLOT,YPLOT)
GO TO 20
15 READ INPUT TAPE 3, 303, NPLOT, (XPLOT(J), YPLOT(J), J = 1, NPLOT)
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XPLOT,YPLOT)
L = -1
CALL LABEL(BCDX,25HX-AXIS (AXIS OF SYMMETRY))
CALL LABEL(BCDY,6HY-AXIS)
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XPLOT,YPLOT)
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XPLOT,YPLOT)
L = 0
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XSAUER,YSAUER)
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XSAUER,YSAUER)
READ INPUT TAPE 3, 300, NTOTAL
NPOINT = 1
NPLOT = 2
30 READ INPUT TAPE 3, 304, (XPLOT(J), YPLOT(J), J = 1, NPLOT)
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XPLOT,YPLOT)
CALL QUIK3L(L,XCL,XCR,YCB,YCT,ISYM,BCDX,BCDY,NPLOT,XPLOT,YPLOT)
```

FORTRAN II PROGRAM LISTING OF SP-37 PLOTTER PROGRAM

```
IF (NPOINT - NTOTAL) 31, 25, 25  
31 NPOINT = NPOINT + 1  
    GO TO 30  
25 IF (NCASE - NDATA) 36, 40, 40  
36 NCASE = NCASE + 1  
    GO TO 35  
40 CONTINUE  
    REWIND 3  
    CALL EXIT  
    END
```

PROGRAM UTILIZATION

Program Input Data

The input data cards should be set up as follows:

- A. First card; NDATA (number of nozzle cases to be run)

FORMAT (I5)

- B. One card; KT, KC, KS (control numbers)

FORMAT (3I5)

KT controls input of thermodynamic data. If it is to be read in (Format explained later), KT = 1. For frozen flow (molecular weight and specific heats ratio being constant), KT = 0. If multiple nozzle cases are being processed and the thermodynamic data are the same as the previous case, KT = 2. (Henceforth, this feature will be referred to as "bypass".)

KC controls the input of the contour points. If the points are to be read into the computer, KC = 1. KC = 0 for bypass.

KS controls the input of the starting line. If points on a starting line are to be read into core, KS = 1. If Hall's starting line (Subroutine OPTIMS) is to be used, KS = 0. KS = 2 for bypass.

- C. One card; NTABLE, NCT, NSONE, N

FORMAT (4I5)

NTABLE is the number of data points in the thermodynamic table (a data point is composed of a pressure, a temperature, a molecular weight, a ratio of specific heats, a Mach number, and a reference Mach number).

NCT is the number of contour points.

NSONE is the number of points on the starting line.

N is the degree of the polynomial to describe various contour segments.

CAUTION. This card must be read into core for each case.

Thus, N may be varied for multiple runs even if the contour points have been bypassed (KC = 0).

D. One card; PA, PC, TC

FORMAT (3 F 10. 7)

PA is the ambient pressure, psia

PC is the chamber pressure, psia

TC is the chamber temperature, °R (for KT ≠ 0, TC is not used by the program and can be assigned any arbitrary value).

E. The number of input cards depend on the value of KT.

1. If KT = 0, one card; G, W

FORMAT (2 F 10. 7)

G is the ratio of specific heats and

W is the molecular weight, lbm/lb-mole.

2. If KT = 1, NTABLE cards

Each card; P, T, FMW, GAMMA, FMVEC, FMSTAR

FORMAT (6 F 10. 7)

P is the pressure, psia.

T is the temperature, °R.

GAMMA is the ratio of specific heats.

FMW is the molecular weight, lbm/lb-mole.

FMVEC is the Mach number.

FMSTAR is the reference Mach number, M^* .

The cards are arranged according to the Mach number,
either in ascending or descending order.

3. If $KT = 2$, no cards are needed.

Note: For $KT = 1$, i. e. for equilibrium composition or
frozen composition with variable specific heats, the required input data
may be obtained from the computer program described in Reference 3.

F. One card; ISYM, XCL, XCR, YCB, YCT

FORMAT (I10, 4 F 10.5)

ISYM is a plotting symbol. Since a "line plot" is desired, it is
recommended that the value 42 be assigned ISYM. XCL and XCR are the
left and right scale limits on the x axis. YCB and YCT are the lower and
upper scale limits on the y-axis.

In most cases, XCL and YCB are both given the values of zero,
XCR an integer just greater than the nozzle length, and YCT an integer just
greater than the exit radius.

G. Two cards

First card; RNX1, RNX2, RPX1, RPX2, RPX3 (in)

Second card; XN1, XN2, XP1, XP2, XP3 (in)

FORMAT (5 F 10.7)

The first card in the set contains the five radii of curvature in
the throat region. The second card contains the ranges of these circular
arcs. The throat geometry is illustrated in FIG 2.

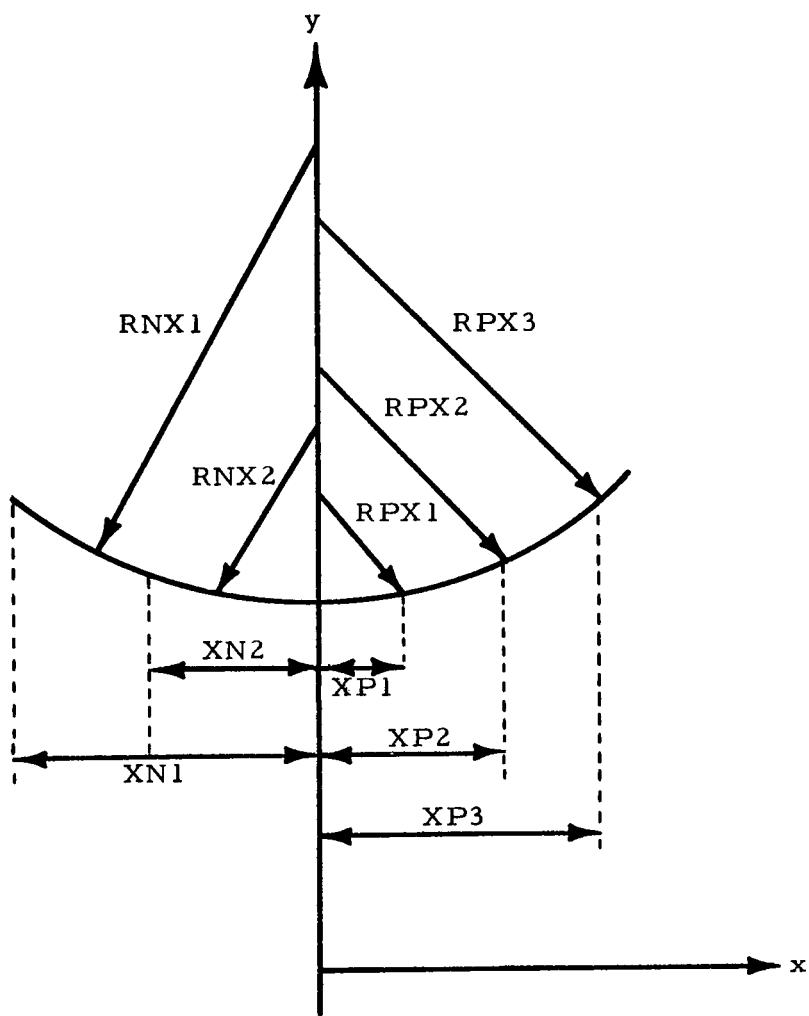


Figure 2. Geometry of Throat

If numerical contour points are used to describe the throat curvature instead of the circular arcs, the five radii of curvature may be given arbitrary values. However, $XP3$ must be smaller than the x-coordinate of the first input contour point; also, $XP3 \geq XP2 \geq XP1 \geq XN2 \geq XN1$. For example, if the x-coordinate of the first input point is zero, set $XP3 = XP2 = XP1 = XN2 = XN1 = 0$.

Note: If the throat is not described by circular arcs, points on the starting line must be specified as input to the program. For this reason, it is recommended that the throat region be described by circular arcs when possible.

H. One card; RT, ARATIO, XNLTH, ANL

FORMAT (4 F 10. 7)

RT is the throat radius, in.

ARATIO is the ratio of the exit area to the throat area.

XNLTH is the nozzle length, in.

The flow net downstream of the left-running characteristic from the axis that intersects the nozzle contour at the exit is not necessary to calculate the performance of the nozzle. Each time a lattice point is calculated on the nozzle axis, the intersection of the left-running characteristic from this point with the nozzle is determined.

In order to calculate the intersection point, the left-running characteristic is assumed to be straight. The flow net downstream of the left-running characteristic is no longer computed if the x-coordinate of the intersection point is greater than "some factor" times the nozzle

length, XNLTH. This factor is ANL. If the left-running characteristic from the cut-off point was actually straight, ANL would be unity. Since the characteristic is not usually straight, $ANL > 1$.

Set $ANL = 5.0$ unless the approximate shape of the cut-off characteristic is known.

I. Input cards depend on the value of KC

1. If $KC = 1$, NCT cards

Each card; X, Y (in)

FORMAT (2 F 10. 7)

X and Y are the coordinates of a contour point. The NCT cards are arranged in ascending order of the X's.

2. If $KC = 0$, no cards are needed, skip to J.

J. Input cards depend on the value of KS.

1. If $KS = 1$, NSONE cards.

Each card; XSAUER, YSAUER, THETAS, FMSAUR

FORMAT (4 F 10. 7)

Each card describes a point on the starting line. XSAUER and YSAUER are the x and y coordinates of the point (in), THETAS is the flow angle in degrees, and FMSAUR is the Mach number at the point. The NSONE cards must be arranged in descending order of the y's.

2. If $KS = 0$, one card; SIGMA

FORMAT (F 10. 7)

SIGMA = 1.

3. If KS = 2, no cards are needed.

Items A through J make up the input cards for the initial case.

If successive cases are to be run, repeat items B through J.

Program Output

After all input data has been read and processed, an echo check will be made to assure that the input information was entered into storage correctly, (the thermodynamic table; points on the starting line, geometrical data, chamber and ambient parameters are printed).

Information about each net point is printed immediately after the point has been computed. This information includes the following:

1. The matrix subscripts, I and J, which identify the point
2. The physical coordinates of the point, in.
3. The Mach number, M
4. The reference Mach number, M*
5. The flow angle at the point, degrees
6. The static temperature at the point, °R
7. The static pressure at the point, psia
8. Magnitude of the velocity vector, ft/sec
9. The mass density at the point, lbm/ft³
10. Convergence tolerance
11. Number of required iterations
12. An "error indicator" which indicates the validity of the point.

The value of the error indicator is either 0 or 1; a value of 0 indicates all calculations proceeded as expected and no errors were

encountered, whereas a value of 1 signifies an error occurred during the calculation of the characteristic point. The most common errors which may be encountered are discussed in the next section.

The characteristic subroutine used to obtain a certain net point can be identified quickly by the values of I and J. Suppose that there are N input points on the starting line. When I is even and J = N - 1, the point is computed by subroutine CASE 2. When I is odd and J = 1, subroutine CASE 4 is used to obtain the point. When I is odd and J = N, the point is computed by CASE 3. All other points are calculated by subroutine CASE 1.

After the computation of the flow net has been terminated (either normally or by an error condition), the thrust, thrust coefficient and specific impulse are printed for each calculated net point on the nozzle contour. Normally, the last point will be located at the nozzle exit. The last value to be printed is the mass flow rate.

Error Conditions

Mesh Size. Sometimes a characteristic solution can not be obtained in the desired degree of accuracy because the mesh size is either too large or too small; however, the latter condition is seldom encountered. If such an error occurs, the number of input points and/or the distribution of the points on the starting line must be changed.

The required computer time is increased greatly if too many input points are used and the flow solutions may be inaccurate if too few points

are specified. The required number of input points may vary from about 10 (low expansion ratios) to as many as 60 (high expansion ratios). About 30 input points are required for bell-shaped nozzles with expansion ratios between 20 and 30. The maximum number of points on the starting line which may be read into core is 60.

Range of Thermodynamic Table. In some cases a thermodynamic independent variable may exceed the range of the thermodynamic table. When this happens, the range of the values in the table must be increased. The range of the thermodynamic table should be considerably greater than the expected range of the variables to be determined since an iteration technique is used to solve for these variables.

Starting Line. The right-running characteristics from all points on the initial value curve must extend downstream of the curve. Bad characteristic solutions will result if this condition is not satisfied. This condition will be satisfied if subroutine OPTIMS is used to establish the starting line.

Hall's transonic solution (subroutine OPTIMS) and many other transonic flow solutions are valid only if the ratio of the radius of curvature at the throat to the throat radius is greater than 1. Therefore, subroutine OPTIMS should be used only when this condition is true.

Shock Waves. Shock waves are frequently present in nozzles that expand and straighten the flow very rapidly, i. e., short nozzles with high expansion ratios. The method of characteristics will not yield valid

solutions across strong shock waves. Therefore, if a strong shock wave is encountered during the computation of the flow net, the flow field downstream of the shock will not be computed.

Characteristic solutions can sometimes be obtained across weak oblique shocks (approximating the actual shock wave by an isentropic compression). The construction of the flow net will continue in this case.

Inaccurate Description of the Nozzle Contour. Any erroneous changes in the flow properties along the contour are propagated along right-running characteristics toward the nozzle axis; furthermore, these errors become magnified as the waves approach the axis. Therefore, it is necessary that the nozzle contour be described accurately.

The most common contour errors result from the following violations:

1. The existence of a discontinuity between two consecutive circular arcs or between the last circular arc and the first numerical contour point.
2. Too few contour points are used to describe a segment of the boundary which has a rapidly changing slope.
3. The specified degree of the polynomial which is used to curve-fit segments of the contour is too great ($N \leq 3$ is recommended).

Sample Problem - Evaluation of a "Perfect Nozzle"

Given Information. A "perfect" nozzle, i. e., a nozzle that produces parallel and uniform flow at the exit, is described by the following data:

I "Frozen" Chemistry

ratio of specific heats = 1.20

molecular weight = 12.0 lbm/lb-mole

chamber temperature = 5700 °R

II Chamber pressure = 630 psia

III Ambient pressure = 0 psia

IV Nozzle length = 12.4244 in

V Throat radius = 1.000 in

VI Area ratio = 7.050

VII Throat Geometry

RNX1 = 4.00 in, for -5.0000 \leq x \leq XN2 = -3.0000

RNX2 = 4.00 in, for -3.0000 \leq x \leq 0

RPX1 = 4.00 in, for 0 \leq x \leq XP1 = 0.1000

RPX2 = 4.00 in, for 0.1000 \leq x \leq XP2 = 0.2000

RPX3 = 4.00 in, for 0.2000 \leq x \leq XP3 = 1.0986

VII Nozzle Contour

The flow-straightening section of the nozzle is described by the numerical data on page 121.

Program Results. Only a sample of the computer printout is shown, planes 7 through 78 are not shown. The characteristic net and streamlines are shown in FIG 3 and 4 respectively.

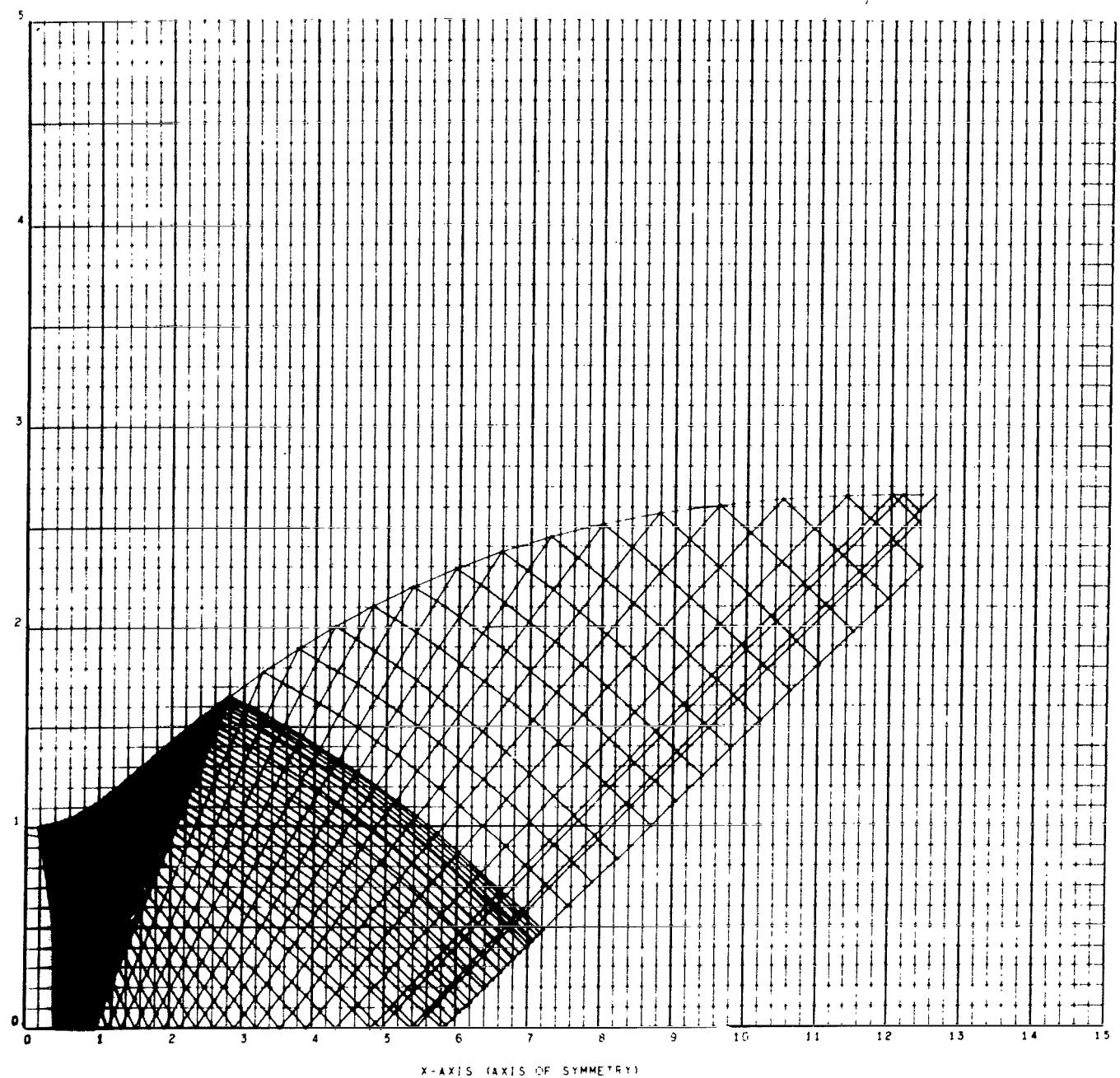


Figure 3 - The Characteristic Net

4464
004 000

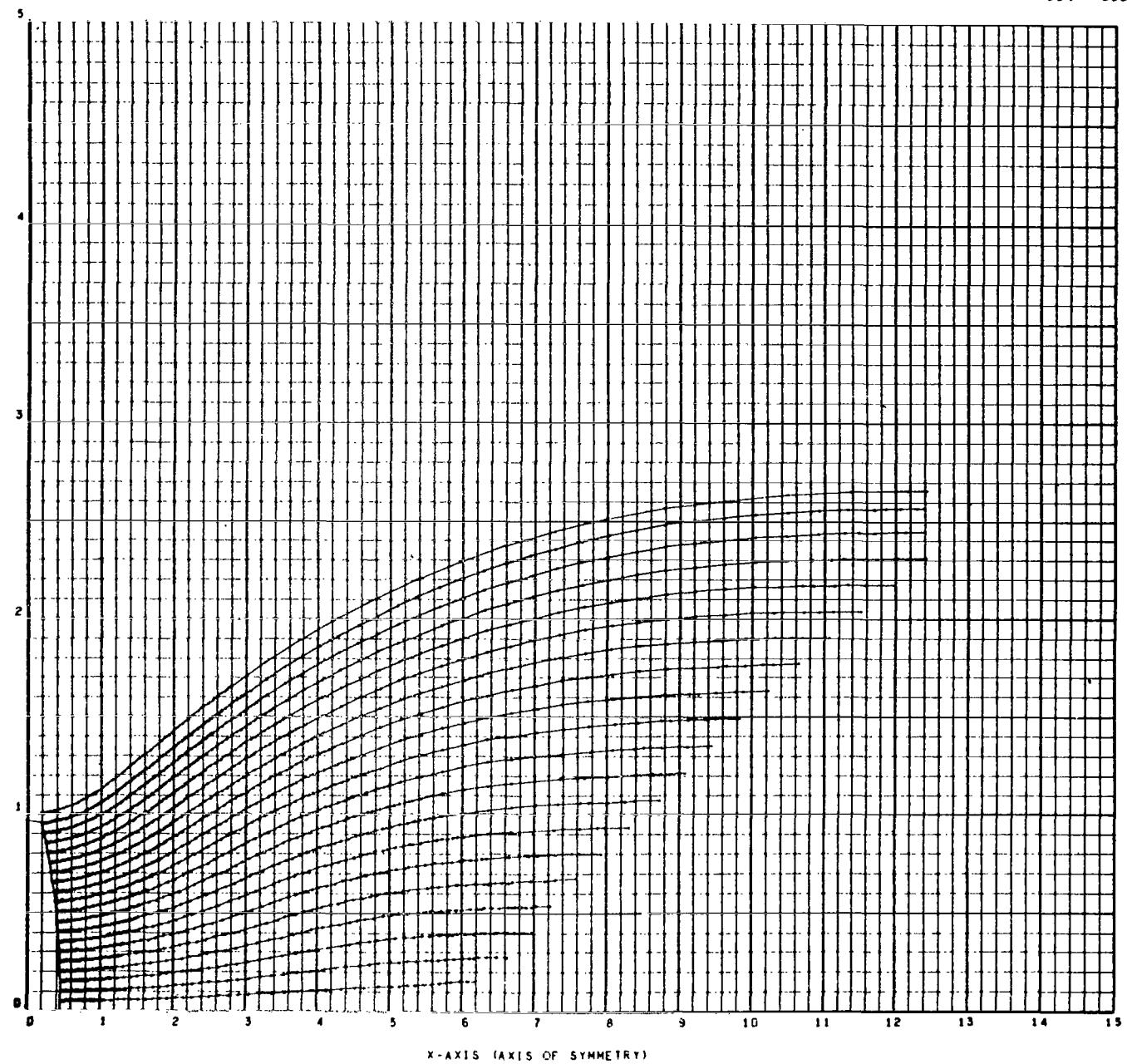


Figure 4 - Streamlines

INPUT DATA ARE AS FOLLOWS

AMBIENT PRESSURE, PA = 0. PSIA
 CHAMBER PRESSURE, PC = 630.0000000 PSIA
 CHAMBER TEMPERATURE, TC = 5700.0000000 DEGREE R
 THROAT RADIUS, RT = 1.0000000 IN.
 NOZZLE LENGTH, XNLTH = 12.4244112 IN.
 AREA RATIO, AE/AT = 7.0500000

RADIi OF THE NOZZLE WALL IN THE NEIGHBORHOOD OF THE THROAT, ASSUMING ALL THE CENTERS OF RADi LiE ON THE Y-AXiS, AND THEIR EFFECTiVE RANGES

RADIUS = 4.000000 IN. FOR X BETWEiN -5.000000 IN. AND -3.000000 IN.
 RADIUS = 4.000000 IN. FOR X BETWEEN -3.000000 IN. AND 0. IN.
 RADIUS = 4.000000 IN. FOR X BETWEEN 0. IN. AND 0.100000 IN.
 RADIUS = 4.000000 IN. FOR X BETWEEN 0.100000 IN. AND 0.200000 IN.
 RADIUS = 4.000000 IN. FOR X BETWEEN 0.200000 IN. AND 1.0985995 IN.

ThERMODYNAMiC DATA

PRESSURE (PSIA)	TEMPERATURE (DEGREE R)	MOLECULAR WT (LB/LB-MORE)	SPECIFIC HEATS RATIO	MACH NU	M*
355.6185760	5181.8181763	12.0000000	1.2000000	1.0000000	1.0000000
317.4730606	5084.7457886	12.0000000	1.2000000	1.1000000	1.0896480
281.0505219	4982.5174561	12.0000000	1.2000000	1.2000000	1.1766968
246.8615570	4875.9623413	12.0000000	1.2000000	1.3000000	1.2610504
215.2551117	4765.8852915	12.0000000	1.2000000	1.4000000	1.3426375
186.4335270	4653.0612183	12.0000000	1.2000000	1.5000000	1.4214106
160.4732742	4538.2165527	12.0000000	1.2000000	1.6000000	1.4973437
137.3482304	4422.0325928	12.0000000	1.2000000	1.7000000	1.5704308
116.9533434	4305.1359453	12.0000000	1.2000000	1.8000000	1.6406837
99.1269722	4188.0969649	12.0000000	1.2000000	1.9000000	1.7081298
83.6704988	4071.4285889	12.0000000	1.2000000	2.0000000	1.7728105
70.3649969	3955.5863953	12.0000000	1.2000000	2.1000000	1.8347785
58.9844012	3840.9703369	12.0000000	1.2000000	2.2000000	1.8940963
49.3055348	3727.9267578	12.0000000	1.2000000	2.3000000	1.9508345
41.1152864	3616.7512817	12.0000000	1.2000000	2.4000000	2.0050696
34.2153044	3507.6923218	12.0000000	1.2000000	2.5000000	2.0568833
28.4247398	3400.9546509	12.0000000	1.2000000	2.6000000	2.1063604
23.5814579	3296.7033081	12.0000000	1.2000000	2.7000000	2.1535879
19.5421124	3195.0672607	12.0000000	1.2000000	2.8000000	2.1986543
16.1814673	3096.1434326	12.0000000	1.2000000	2.9000000	2.2416481
13.3911843	3000.0000000	12.0000000	1.2000000	3.0000000	2.2826577
11.0783492	2906.6802673	12.0000000	1.2000000	3.1000000	2.3217702
9.1638405	2816.2055359	12.0000000	1.2000000	3.2000000	2.3590713
7.5807113	2728.5782776	12.0000000	1.2000000	3.3000000	2.3946446
6.2726070	2643.7847900	12.0000000	1.2000000	3.4000000	2.4285714
5.1923085	2561.7977295	12.0000000	1.2000000	3.5000000	2.4609306
4.3004043	2482.5783997	12.0000000	1.2000000	3.6000000	2.4917983
3.5641027	2406.0795217	12.0000000	1.2000000	3.7000000	2.5212478
2.9561972	2332.2422485	12.0000000	1.2000000	3.8000000	2.5493492
2.4541637	2261.0075378	12.0000000	1.2000000	3.9000000	2.5761700
2.0393910	2192.3076182	12.0000000	1.2000000	4.0000000	2.6017745
1.6965229	2126.0723817	12.0000000	1.2000000	4.1000000	2.6262241
1.4129030	2062.2286377	12.0000000	1.2000000	4.2000000	2.6495774
1.1781103	2000.7020111	12.0000000	1.2000000	4.3000000	2.6718899
0.9835678	1941.4169006	12.0000000	1.2000000	4.4000000	2.6932148
0.8222206	1884.2975464	12.0000000	1.2000000	4.4999999	2.7136021
0.6882654	1829.2683105	12.0000000	1.2000000	4.6000000	2.7330995
0.5769290	1776.2543182	12.0000000	1.2000000	4.6999999	2.7517523
0.4842843	1725.1816101	12.0000000	1.2000000	4.8000000	2.7696032
0.4070997	1675.9776459	12.0000000	1.2000000	4.9000000	2.7866928
0.3421144	1628.5114417	12.0000000	1.2000000	4.9999999	2.8030595
0.2889362	1582.8936615	12.0000000	1.2000000	5.1000000	2.8187396
0.2439579	1538.8769073	12.0000000	1.2000000	5.1999999	2.8337673
0.2062684	1496.4557800	12.0000000	1.2000000	5.3000000	2.8481753
0.1746966	1455.5669098	12.0000000	1.2000000	5.4000000	2.861942
0.1481649	1416.1490936	12.0000000	1.2000000	5.4999999	2.8752531
0.1258512	1378.1431274	12.0000000	1.2000000	5.6000000	2.8879794
0.1070583	1341.4921265	12.0000000	1.2000000	5.6999999	2.9001992
0.0912078	1306.1411743	12.0000000	1.2000000	5.8000000	2.9119369
0.0778199	1272.0374756	12.0000000	1.2000000	5.9000000	2.9232158

CRITICAL SONIC VELOCITY, C* = 5077.4486694 FT/SEC

POINTS DEFINING THE NOZZLE CONTOUR

X (IN.)	Y (IN.)
------------	------------

0.1875000	1.0043969
0.2482997	1.0077140
0.3105105	1.0120703
0.3736136	1.0174866
0.4375299	1.0240010
0.5022379	1.0316555
0.5677122	1.0404921
0.6339743	1.0505599
0.7010348	1.0619103
0.7689534	1.0746070
0.8377796	1.0887181
0.9075994	1.1043276
0.9784e04	1.1215239
1.0505179	1.1404129
1.0985995	1.1536228
1.2111470	1.1659702
1.3662025	1.2202889
1.5445205	1.2602436
1.7399359	1.3459249
1.9488324	1.4092923
2.1689202	1.4749955
2.3986719	1.5419666
2.6370542	1.6093353
2.8834364	1.6764904
3.1369607	1.7428416
3.3975034	1.8079808
3.6653240	1.8717395
3.9391610	1.9336131
4.2202007	1.9936768
4.5063357	2.0513139
4.8002039	2.1069337
5.0983530	2.1597447
5.4043506	2.2103580
5.7143373	2.2580161
6.0321419	2.3032887
6.3536528	2.3454908
6.6831174	2.3852094
7.0157009	2.4217756
7.3564383	2.4558376
7.6996214	2.4867396
8.0505751	2.5150817
8.4046767	2.5404199
8.7651365	2.5631161
9.1300080	2.5830347
9.4992250	2.6002794
9.8744137	2.6150153
10.2516994	2.6271261
10.6354506	2.6369932
11.0210290	2.6444740
11.4112419	2.6499664
11.8049258	2.6535136
12.2009778	2.6554474
12.4244112	2.6558359

POINTS ON THE STARTING LINE

MACH NO. M*	SPECIFIC HEAT RATIO PRESSURE = TEMPERATURE = SONIC VELOCITY = VELOCITY = DENSITY = MOLECULAR WEIGHT =	1.1659033 1.1470160 1.2000000 293.4693832 PSIA 5017.3738403 DEGREE R 4996.2330322 FT/SEC 5825.1247559 FT/SEC 0.0653621 LBM/CU-FT 12.0000000 LBM/LB-MOLE
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X (IN.)	Y (IN.)	THETA (DEGREES)
0.1716562	1.0036849	2.4595458
0.2012316	0.9535007	2.4950946
0.2293701	0.9033164	2.4969516
0.2557950	0.8531322	2.4698824
0.2805219	0.8029479	2.4179850
0.3035705	0.7527637	2.3447543
0.3249632	0.7025794	2.2531651
0.3447248	0.6523952	2.1457487
0.3628814	0.6022109	2.0246637
0.3794597	0.5520267	1.8917577
0.3944868	0.5018425	1.7466238
0.4079893	0.4516582	1.5966474
0.4199929	0.4014740	1.4370477
0.4305216	0.3512897	1.2709130
0.4395979	0.3011055	1.0992268
0.4472419	0.2509212	0.9229019
0.4534711	0.2007370	0.7427799
0.4583003	0.1505527	0.5596664
0.4617413	0.1003685	0.3743336
0.4638024	0.0501842	0.1875324
0.4644889	-0.	-0.

CALCULATED POINTS ARRANGED ROW WISE

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG_R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
2	1	0.2028788	0.9565344	1.1677367	1.1486119	2.5352014	5015.5	292.80	5833.2	0.065238	-0.0000000	2	0
2	2	0.2316969	0.9075978	1.1685399	1.1493111	2.5542573	5014.7	292.51	5836.7	0.065183	0.	2	0
2	3	0.2589077	0.8588484	1.1692300	1.1499119	2.5406397	5014.0	292.26	5839.8	0.065136	-0.0000000	2	0
2	4	0.2844007	0.8100502	1.1698238	1.1504267	2.4995439	5013.4	292.04	5842.4	0.065096	0.0000001	1	0
2	5	0.3081982	0.7612060	1.1703354	1.1508741	2.4348923	5012.8	291.86	5844.6	0.065061	0.0000001	1	0
2	6	0.3303250	0.7123180	1.1707768	1.1512584	2.3500072	5012.4	291.69	5846.6	0.065031	0.0000001	1	0
2	7	0.3508075	0.6633885	1.1711585	1.1515906	2.2477203	5012.0	291.56	5848.2	0.065005	0.0000000	1	0
2	8	0.3696733	0.6144197	1.1714690	1.1518783	2.1304408	5011.7	291.43	5849.7	0.064983	0.0000000	1	0
2	9	0.3869509	0.5654136	1.1717755	1.1521277	2.0002246	5011.4	291.33	5851.0	0.064963	0.0000000	1	0
2	10	0.4026685	0.5163726	1.1720240	1.1523440	1.8588368	5011.1	291.24	5852.1	0.064947	0.0000000	1	0
2	11	0.4168540	0.4672989	1.1722392	1.1525314	1.7078009	5010.9	291.16	5853.0	0.064932	0.0000000	1	0
2	12	0.4295343	0.4181950	1.1724251	1.1526931	1.5484475	5010.7	291.09	5853.0	0.064919	0.0000000	1	0
2	13	0.4407348	0.3690635	1.1725845	1.1528320	1.3819520	5010.5	291.04	5854.5	0.064909	0.0000000	1	0
2	14	0.4504794	0.3199071	1.1727201	1.1529500	1.2093702	5010.4	290.99	5855.1	0.064899	-0.0000000	1	0
2	15	0.4587894	0.2707288	1.1728336	1.1530488	1.0316603	5010.3	290.95	5855.0	0.064892	-0.0000000	1	0
2	16	0.4656841	0.2215317	1.1729264	1.1531296	0.8497096	5010.2	290.91	5856.0	0.064885	0.0000000	1	0
2	17	0.4711796	0.1723189	1.1729996	1.1531933	0.6643523	5010.1	290.86	5856.3	0.064880	-0.0000000	1	0
2	18	0.4752894	0.1230938	1.1730394	1.1532405	0.4763803	5010.1	290.86	5856.0	0.064877	-0.0000000	1	0
2	19	0.4780235	0.0738598	1.1730896	1.1532718	0.2865685	5010.0	290.85	5856.7	0.064874	0.0000000	1	0
2	20	0.4793892	0.0246202	1.1731208	1.1532987	0.0949153	5010.0	290.84	5856.9	0.064872	0.0000000	4	0
3	1	0.2311783	1.0066860	1.2017026	1.1781330	3.3132315	4980.7	280.47	5982.0	0.062926	0.0000000	4	0
3	2	0.2334490	0.9108040	1.1704041	1.1509339	2.5944336	5012.8	291.63	5844.9	0.065057	-0.0000000	2	0
3	3	0.2613841	0.8633624	1.1719660	1.1522413	2.5980671	5011.2	291.26	5851.5	0.064955	0.0000001	1	0
3	4	0.2677012	0.8160393	1.1731945	1.1533629	2.5704131	5009.9	290.81	5857.2	0.064867	0.0000001	1	0
3	5	0.3122974	0.7686063	1.1743014	1.1543265	2.5165412	5008.8	290.41	5862.1	0.064792	0.0000000	1	0
3	6	0.3352009	0.7210717	1.1752544	1.1551560	2.4402052	5007.8	290.06	5866.2	0.064727	0.0000000	1	0
3	7	0.3564413	0.6734422	1.1760762	1.1558714	2.3445908	5007.0	289.76	5869.9	0.064671	0.0000000	1	0
3	8	0.3760486	0.6257244	1.1767862	1.1564895	2.2324102	5006.2	289.51	5873.0	0.064623	0.0000000	1	0
3	9	0.3940534	0.5779241	1.1774007	1.1570243	2.1059729	5005.6	289.28	5875.7	0.064581	0.0000000	1	0
3	10	0.4104857	0.5300469	1.1779328	1.1574876	1.9672510	5005.1	289.09	5878.0	0.064544	0.0000000	1	0
3	11	0.4253751	0.4820984	1.1783936	1.1578866	1.8179432	5004.6	288.92	5880.0	0.064513	-0.0000000	1	0
3	12	0.4387499	0.4340840	1.1787917	1.1582352	1.6595173	5004.2	288.78	5881.8	0.064486	-0.0000000	1	0
3	13	0.4506372	0.3860096	1.1791342	1.1585333	1.4932604	5003.8	288.65	5883.3	0.064463	-0.0000000	1	0
3	14	0.4610621	0.3376809	1.1794266	1.1587879	1.3203154	5003.5	288.54	5884.6	0.064443	0.0000000	1	0
3	15	0.4700477	0.2897040	1.1796733	1.1590026	1.1417112	5003.3	288.45	5885.6	0.064426	-0.0000000	1	0
3	16	0.4776145	0.2414653	1.1798775	1.1591804	0.9583850	5003.1	288.38	5886.5	0.064412	-0.0000000	1	0
3	17	0.4837804	0.1932312	1.1800418	1.1593234	0.7712104	5002.9	288.32	5887.3	0.064401	-0.0000000	1	0
3	18	0.4885603	0.1449487	1.1801678	1.1594331	0.5810099	5002.8	288.27	5887.8	0.064392	-0.0000000	1	0
3	19	0.4919659	0.0966445	1.1802570	1.1595108	0.3885670	5002.7	288.24	5888.2	0.064386	-0.0000000	1	0
3	20	0.4940066	0.0483249	1.1803201	1.1595657	0.1942840	5002.6	288.22	5888.5	0.064382	-0.0000000	1	0
3	21	0.4946830	0.	1.1802205	1.1594790	0.	5002.7	288.25	5888.0	0.064389	0.	2	0
4	1	0.2635999	0.9638791	1.2050010	1.1809153	3.3742009	4977.2	279.34	5996.3	0.062718	-0.0000000	3	0
4	2	0.2632416	0.8667296	1.1737976	1.1538879	2.6382852	5009.3	290.59	5859.8	0.064826	0.0000001	1	0
4	3	0.2903273	0.8207695	1.1759055	1.1557228	2.6279406	5007.1	289.83	5869.1	0.064683	0.0000000	1	0
4	4	0.3157852	0.7748473	1.1777110	1.1572945	2.5874964	5005.3	289.17	5877.0	0.064560	0.0000000	1	0
4	5	0.3395192	0.7287454	1.1792609	1.1586437	2.5219161	5003.7	288.60	5883.8	0.064454	0.0000000	1	0
4	6	0.3615635	0.6824799	1.1805942	1.1598043	2.4348245	5002.4	288.12	5889.7	0.064363	0.0000000	1	0
4	7	0.3819520	0.6360640	1.1817432	1.1608045	2.3292896	5001.2	287.70	5894.7	0.064285	0.0000000	1	0
4	8	0.4007182	0.5895097	1.1827354	1.1616682	2.2079245	5000.2	287.34	5899.1	0.064217	-0.0000000	1	0
4	9	0.4178948	0.5428280	1.1835933	1.1624149	2.0729593	4999.3	287.03	5902.8	0.064158	-0.0000000	1	0
4	10	0.44335137	0.4960288	1.1843352	1.1630608	1.9262991	4998.5	286.76	5906.1	0.064108	-0.0000000	1	0
4	11	0.4476052	0.4491219	1.1849764	1.1636189	1.7695873	4997.9	286.52	5908.9	0.064064	-0.0000000	1	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATI
4	12	0.4601981	0.4021168	1.1855287	1.1640997	1.6042490	4997.3	286.32	5911.3	0.064026	-0.0000000	1	0
4	13	0.4713192	0.3550229	1.1860017	1.1645115	1.4315378	4996.8	286.15	5913.4	0.063994	-0.0000000	1	0
4	14	0.4809932	0.3078500	1.1864031	1.1648608	1.2525712	4996.4	286.00	5915.2	0.063966	-0.0000000	1	0
4	15	0.4892423	0.2606078	1.1867386	1.1651529	1.0683550	4996.1	285.88	5916.6	0.063943	-0.0000000	1	0
4	16	0.4960858	0.2133064	1.1870125	1.1653913	0.8798141	4995.8	285.78	5917.8	0.063925	-0.0000000	1	0
4	17	0.5015403	0.1659562	1.1872282	1.1655791	0.6878084	4995.6	285.70	5918.8	0.063910	-0.0000000	1	0
4	18	0.5056192	0.1185676	1.1873881	1.1657183	0.4931521	4995.4	285.64	5919.5	0.063899	0.0000000	1	0
4	19	0.5083338	0.0711502	1.1875020	1.1658175	0.2963545	4995.3	285.60	5920.0	0.063891	-0.0000000	1	0
4	20	0.5096853	0.0237231	1.1875309	1.1658426	0.0993828	4995.3	285.59	5920.1	0.063889	0.0000000	4	0
5	1	0.2920224	1.0106739	1.2396448	1.2101386	4.1866375	4940.3	267.50	6145.8	0.060507	-0.	4	0
5	2	0.2952529	0.9225539	1.2089885	1.1842790	3.4193495	4972.9	277.98	6013.6	0.062465	-0.0000000	3	0
5	3	0.2922903	0.8242862	1.1778211	1.1573903	2.6681828	5005.2	289.13	5877.5	0.064552	0.0000000	1	0
5	4	0.3185605	0.7797775	1.1804532	1.1596815	2.6450993	5002.5	288.17	5889.1	0.064373	0.0000000	1	0
5	5	0.3431933	0.7352179	1.1827051	1.1616418	2.5929332	5000.2	287.35	5898.9	0.064219	-0.0000000	1	0
5	6	0.3660995	0.6904036	1.1846368	1.1633233	2.5165764	4998.2	286.65	5907.4	0.064087	-0.0000000	1	0
5	7	0.3873184	0.6453598	1.1862974	1.1647688	2.4195414	4996.5	286.04	5914.7	0.063974	-0.0000000	1	0
5	8	0.4068683	0.6001079	1.1877277	1.1660139	2.3047992	4995.1	285.52	5921.0	0.063876	-0.0000000	1	0
5	9	0.4248457	0.5546664	1.1889618	1.1670882	2.1748849	4993.8	285.07	5926.4	0.063791	-0.0000000	1	0
5	10	0.4412254	0.5090521	1.1900276	1.1680160	2.0319623	4992.7	284.68	5931.0	0.063718	-0.0000000	1	0
5	11	0.4560606	0.4632803	1.1909479	1.1688170	1.8778840	4991.8	284.35	5935.1	0.063655	-0.0000000	1	0
5	12	0.4693823	0.4173653	1.1917411	1.1695075	1.7142487	4991.0	284.06	5938.5	0.063601	-0.0000000	1	0
5	13	0.4812195	0.3713214	1.1924219	1.1701002	1.5424500	4990.3	283.81	5941.5	0.063554	-0.0000000	1	0
5	14	0.4915986	0.3251622	1.1930018	1.1706050	1.3637165	4989.7	283.60	5944.0	0.063515	-0.0000000	1	0
5	15	0.5005436	0.2789015	1.1934901	1.1710300	1.1791395	4989.2	283.42	5946.2	0.063481	-0.0000000	1	0
5	16	0.5080755	0.2325533	1.1938936	1.1713813	0.9897150	4988.8	283.27	5947.9	0.063453	-0.0000000	1	0
5	17	0.5142127	0.1861316	1.1942177	1.1716633	0.7963536	4988.4	283.16	5949.4	0.063431	-0.0000000	1	0
5	18	0.5189701	0.1396508	1.1944661	1.1718796	0.5999048	4988.2	283.07	5950.4	0.063414	-0.0000000	1	0
5	19	0.5223609	0.0931236	1.1946489	1.1720387	0.4009522	4988.0	283.00	5951.2	0.063402	-0.0000000	1	0
5	20	0.5243869	0.0465747	1.1947347	1.1721134	0.2012119	4987.9	282.97	5951.6	0.063396	0.0000000	1	0
5	21	0.5250649	0.	1.1947321	1.1721112	0.	4987.9	282.97	5951.6	0.063396	0.	2	0
6	1	0.3253854	0.9717128	1.2440492	1.2138538	4.2326427	4935.6	265.99	6164.7	0.060224	-0.0000000	3	0
6	2	0.3261661	0.8826620	1.2135725	1.1881457	3.4501633	4968.1	276.41	6033.4	0.062174	-0.0000000	3	0
6	3	0.3206288	0.7834320	1.1823900	1.1613675	2.6853473	5000.5	287.46	5897.6	0.064241	-0.0000000	1	0
6	4	0.3461171	0.7403321	1.1854751	1.1640530	2.6505936	4997.4	286.34	5911.1	0.064030	-0.0000000	1	0
6	5	0.3699586	0.6970880	1.1881119	1.1663484	2.5876371	4994.7	285.38	5922.6	0.063849	-0.0000000	1	0
6	6	0.3920701	0.6535114	1.1903723	1.1683160	2.5013190	4992.4	284.56	5932.5	0.063695	-0.0000000	1	0
6	7	0.4124963	0.6096380	1.1923144	1.1700065	2.3950572	4990.4	283.85	5941.0	0.063562	-0.0000000	1	0
6	8	0.4312794	0.5654980	1.1939860	1.1714616	2.2717464	4988.7	283.24	5948.3	0.063447	-0.0000000	1	0
6	9	0.4484586	0.5211175	1.1954268	1.1727159	2.1338573	4987.2	282.72	5954.6	0.063348	-0.0000000	1	0
6	10	0.4640706	0.4765198	1.1966694	1.1737975	1.9835021	4985.9	282.26	5960.1	0.063263	-0.0000000	1	0
6	11	0.4781497	0.4317260	1.1977401	1.1747295	1.8224885	4984.8	281.87	5964.7	0.063189	-0.0000000	1	0
6	12	0.4907274	0.3867557	1.1986599	1.1755303	1.6523861	4983.9	281.54	5968.8	0.063126	-0.0000000	1	0
6	13	0.5018325	0.3416279	1.1994458	1.1762144	1.4745613	4983.1	281.25	5972.4	0.063072	-0.0000000	1	0
6	14	0.5114911	0.2963610	1.2001146	1.1767934	1.2902164	4982.4	281.01	5975.1	0.063027	-0.0000000	1	0
6	15	0.5197263	0.2509732	1.2006869	1.1772763	1.1004353	4981.8	280.82	5977.6	0.062991	-0.0000000	1	0
6	16	0.5265579	0.2054828	1.2011535	1.1776698	0.9061962	4981.3	280.66	5979.0	0.062961	-0.0000000	1	0
6	17	0.5320262	0.1599079	1.2015204	1.1779793	0.7084009	4980.9	280.53	5981.2	0.062938	-0.0000000	1	0
6	18	0.5360757	0.1142651	1.2017987	1.1782141	0.5076964	4980.6	280.44	5982.4	0.062920	-0.0000000	1	0
6	19	0.5387795	0.0685842	1.2019613	1.1783512	0.3057035	4980.4	280.38	5983.1	0.062910	-0.0000000	1	0
6	20	0.5401342	0.0228644	1.2020619	1.1784361	0.1018421	4980.3	280.35	5983.6	0.062904	0.0000000	4	0
7	1	0.3537755	1.0156754	1.2783090	1.2427532	5.0740904	4899.1	254.28	6311.0	0.058001	-0.0000001	3	0
7	2	0.3580062	0.9340594	1.2490085	1.2180372	4.2640274	4930.3	264.30	6185.9	0.059904	-0.0000000	3	0
7	3	0.3563688	0.8442230	1.2186722	1.1924474	3.4679156	4962.6	274.67	6055.5	0.061849	-0.0000000	3	0
7	4	0.3482902	0.7441133	1.1874306	1.1657553	2.6908332	4995.4	285.63	5919.7	0.063896	-0.0000001	1	0
7	5	0.3730297	0.7023709	1.1909067	1.1687812	2.6453408	4991.8	284.36	5934.9	0.063658	-0.0000001	1	0
7	6	0.3961125	0.6603893	1.1938753	1.1713653	2.5724106	4988.8	283.28	5947.9	0.063455	-0.0000001	1	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
78	7	3.8295361	1.2389071	2.5371411	2.0752597	9.8226689	3468.0	32.06	10538.8	0.010332	0.0000001	2	0
78	8	4.0471193	1.1646537	2.6038662	2.1081863	9.1677011	3396.9	28.24	10704.5	0.009289	0.0000001	2	0
78	9	4.2406987	1.0717242	2.6517265	2.1307895	7.9510152	3347.0	25.92	10820.9	0.008654	0.0000001	2	0
78	10	4.4313905	0.9736362	2.6981665	2.1527220	6.7093970	3298.6	23.67	10930.5	0.008019	-0.0000000	3	0
78	11	4.6554497	0.8880680	2.7648523	2.1828145	5.9444460	3230.8	20.96	11084.9	0.007250	-0.0000000	3	0
78	12	4.8483015	0.7801551	2.8119245	2.2037811	4.6838953	3183.3	19.14	11190.4	0.006720	0.0000001	2	0
78	13	5.0409374	0.6664476	2.8589258	2.2239887	3.4018133	3136.8	17.56	11294.0	0.006256	-0.0000000	2	0
78	14	5.2731262	0.5626379	2.9204517	2.2500353	2.5368770	3076.5	15.61	11425.7	0.005670	-0.0000000	3	0
78	15	5.4731308	0.4317705	2.9624217	2.2672470	1.3438138	3036.1	14.44	11513.6	0.005315	0.0000000	3	0
78	16	5.6528947	0.3164141	2.9721296	2.2712282	1.0279827	3026.8	14.17	11533.6	0.005231	0.0000000	3	0
78	17	5.6569110	0.2705060	2.9761437	2.2736945	1.2067213	3021.0	14.00	11545.9	0.005179	-0.0000000	2	0
78	18	5.8084641	0.1630133	2.9766187	2.2730691	1.7826027	3022.5	14.04	11542.8	0.005192	0.0000000	4	0
78	19	5.7450725	0.1146683	2.9797847	2.2743675	1.5835010	3019.4	13.96	11549.2	0.005165	-0.0000001	3	0
78	20	5.8776100	0.0146694	3.0199292	2.2904525	-3.4248706	2981.4	12.93	11630.9	0.004846	-0.0219269	7	0
79	1	2.7804860	1.6484297	2.2748711	1.9365768	15.2464503	3756.3	51.74	9834.3	0.015392	0.0000000	2	0
79	2	2.7819377	1.6330988	2.2745513	1.9363954	15.1136401	3756.7	51.77	9833.4	0.015399	0.0000000	1	0
79	3	3.0165619	1.5664124	2.3289243	1.9665217	14.0107030	3695.8	46.94	9986.5	0.014192	-0.0000000	3	0
79	4	3.2386791	1.4955265	2.3805081	1.9944982	12.8834105	3638.4	42.71	10128.2	0.013118	-0.0000000	3	0
79	5	3.4630010	1.4289518	2.4495325	2.0307343	12.3087151	3562.7	37.70	10312.9	0.011824	-0.0000000	3	0
79	6	3.6715592	1.3510197	2.4981576	2.0559287	11.1501843	3509.7	34.34	10439.0	0.010935	0.	3	0
79	7	3.8743222	1.2680586	2.5468113	2.0800442	9.9659019	3457.7	31.50	10563.2	0.010182	-0.0000000	3	0
79	8	4.0720456	1.1799848	2.5936071	2.1031974	8.7563547	3407.8	28.79	10679.3	0.009442	-0.0000000	3	0
79	9	4.2962359	1.1039615	2.6620958	2.1356867	8.0970728	3336.2	25.42	10845.6	0.008514	-0.0000000	3	0
79	10	4.4922194	1.0066540	2.7088626	2.1575821	6.8589181	3287.7	23.22	10955.6	0.007894	0.0000000	3	0
79	11	4.6860452	0.9036626	2.7559197	2.1787889	5.5923517	3239.9	21.32	11064.6	0.007355	0.0000000	3	0
79	12	4.9197626	0.8143119	2.8224948	2.2083257	4.8272185	3172.8	18.79	11214.0	0.006617	0.0000001	2	0
79	13	5.1175243	0.7004053	2.8886649	2.2282620	3.5483011	3126.9	17.23	11315.5	0.006157	0.0000000	2	0
79	14	5.3155149	0.5801505	2.9129630	2.2469642	2.2564792	3083.7	15.82	11409.7	0.005733	0.0000000	3	0
79	15	5.5585957	0.4707772	2.9705761	2.2705911	1.4836134	3028.3	14.21	11530.4	0.005244	0.0000000	3	0
79	16	5.7392977	0.3491006	2.9796529	2.2743134	1.1446748	3019.6	13.96	11548.9	0.005166	-0.0000000	3	0
79	17	5.7191529	0.2940636	2.9749519	2.2723856	1.0254173	3024.1	14.09	11539.3	0.005207	-0.0000000	2	0
79	18	5.8887350	0.1943513	2.9813843	2.2750235	1.6406798	3017.9	13.91	11552.5	0.005151	-0.0000000	4	0
79	19	5.8420920	0.1521231	2.9908336	2.2788986	1.4929517	3008.8	13.65	11571.6	0.005069	0.0000000	4	0
79	20	5.9647288	0.0431391	3.0500934	2.3022505	1.0893254	2953.3	12.23	11691.4	0.004629	-0.0000000	13	0
79	21	5.9647288	0.0431391	0.	0.	1.0893254	0.	0.	0.	-0.0000000	-0.0000000	13	0
80	1	2.7960451	1.6454500	2.2786676	1.9387309	15.1796757	3752.0	51.37	9845.1	0.015300	-0.0000000	1	0
80	2	3.0367676	1.5830399	2.3346540	1.9696292	14.1020973	3689.4	46.47	10002.4	0.014074	0.0000001	3	0
80	3	3.2645263	1.5155324	2.3871982	1.9981266	12.9919312	3631.0	42.16	10146.2	0.012976	-0.0000000	3	0
80	4	3.4822384	1.4430501	2.4380834	2.0248021	11.8534563	3575.2	38.49	10282.6	0.012030	-0.0000000	3	0
80	5	3.7085750	1.3767158	2.5068177	2.0602656	11.2794461	3500.4	33.82	10461.3	0.010797	0.0000000	3	0
80	6	3.9168560	1.2957971	2.5559855	2.0845833	10.1040540	3447.9	30.97	10586.3	0.010039	-0.0000000	3	0
80	7	4.1201233	1.2094052	2.6032200	2.1078811	8.9023297	3397.6	28.27	10702.9	0.009298	0.0000001	2	0
80	8	4.3194268	1.1173497	2.6507157	2.1303121	7.6704539	3348.1	25.97	10818.5	0.008667	0.0000000	3	0
80	9	4.5516753	1.0390808	2.7194412	2.1623494	7.0093234	3276.9	22.80	10980.4	0.007774	0.0000000	2	0
80	10	4.7511162	0.9366807	2.7663834	2.1835045	5.7485595	3229.2	20.90	11088.3	0.007232	0.0000001	2	0
80	11	4.9486720	0.8281544	2.8121076	2.2038598	4.4571192	3183.1	19.14	11190.8	0.006718	0.0000001	2	0
80	12	5.1937603	0.7343288	2.8789946	2.2326171	3.7030770	3116.9	16.89	11337.3	0.006054	0.0000000	2	0
80	13	5.3971192	0.6137540	2.9228611	2.2510234	2.4215118	3074.2	15.54	11430.8	0.005650	-0.0000001	2	0
80	14	5.5999829	0.4866892	2.9615670	2.2668965	1.1814051	3037.0	14.46	11511.8	0.005322	0.0000000	3	0
80	15	5.8269622	0.3823936	2.9880768	2.2777680	1.2848502	3011.5	13.72	11566.0	0.005093	-0.0000000	3	0
80	16	5.8059162	0.3268648	2.9826032	2.2755234	1.1387402	3016.7	13.88	11554.9	0.005140	0.0000000	2	0
80	17	5.9487402	0.2175198	2.9771104	2.2732708	1.3585743	3022.0	14.03	11543.8	0.005188	0.0000000	4	0
80	18	5.9231290	0.1831386	2.9945898	2.2804390	1.3529261	3005.2	13.54	11579.2	0.005036	-0.0000000	3	0
80	19	6.0631169	0.0788345	3.0483490	2.3015682	0.5021873	2954.9	12.27	11688.0	0.004641	0.0000001	5	0
81	1	2.8080094	1.6559316	2.2824610	1.9408832	15.2464503	3747.8	51.00	9855.8	0.015208	0.0000000	2	0
81	2	3.0521211	1.5956838	2.3388818	1.9719221	14.1679517	3684.7	46.12	10014.1	0.013987	0.0000000	3	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR- INDICAT[
81	3	3.2864446	1.5325167	2.3928319	2.0011820	13.0835739	3624.7	41.70	10161.4	0.012857	0.0000000	3	0
81	4	3.5101873	1.4634208	2.4449679	2.0283692	11.9628454	3567.7	38.01	10300.8	0.011906	-0.0000000	3	0
81	5	3.7258371	1.3886323	2.4943667	2.0539645	10.8111993	3513.8	34.60	10429.3	0.011005	-0.0000000	3	0
81	6	3.9566986	1.3218301	2.5645630	2.0888272	10.2350125	3438.8	30.48	10607.7	0.009904	-0.0000000	3	0
81	7	4.1658165	1.2374280	2.6126369	2.1123285	9.0430574	3387.8	27.81	10726.1	0.009174	-0.0000000	3	0
81	8	4.3710147	1.1469743	2.6604192	2.1348949	7.8205481	3338.0	25.50	10841.7	0.008536	-0.0000000	3	0
81	9	4.5727277	1.0503990	2.7066336	2.1565774	6.5659087	3290.0	23.31	10950.4	0.007919	-0.0000000	3	0
81	10	4.8147631	0.9690764	2.7766727	2.1881415	5.9054180	3218.8	20.48	11111.5	0.007112	0.0000000	3	0
81	11	5.0184796	0.8611018	2.8227395	2.2084309	4.6230319	3172.6	18.78	11214.5	0.006614	0.0000001	2	0
81	12	5.2209156	0.7463483	2.8674897	2.2276707	3.3118389	3128.3	17.27	11312.6	0.006171	-0.0000001	2	0
81	13	5.4784259	0.6473962	2.9330289	2.2551931	2.5938681	3064.4	15.26	11452.3	0.005565	-0.0000001	2	0
81	14	5.6867780	0.5159718	2.9710122	2.2707699	1.3751248	3027.9	14.20	11531.3	0.005241	-0.0000000	3	0
81	15	5.8659042	0.3971097	2.9776573	2.2734950	0.9425547	3021.5	14.01	11544.9	0.005183	0.0000000	3	0
81	16	5.8940075	0.3602711	2.9911661	2.2790349	1.2765911	3008.5	13.64	11572.3	0.005066	-0.0000000	1	0
81	17	6.0356932	0.2508758	2.9856656	2.2767793	1.4205745	3013.8	13.79	11561.2	0.005114	0.0000001	3	0
81	18	5.9834741	0.2059849	2.9894910	2.2783480	1.0692376	3010.1	13.68	11568.9	0.005080	0.0000000	2	0
81	19	6.1463643	0.1084158	3.0461533	2.3007094	0.3074343	2956.9	12.32	11683.6	0.004657	-0.0000000	5	0
82	1	3.0652115	1.6064714	2.3427962	1.9740451	14.2348188	3680.3	45.80	10025.0	0.013907	0.0000000	3	0
82	2	3.3030785	1.5454178	2.3969841	2.0034340	13.1495444	3620.1	41.36	10172.6	0.012768	-0.0000000	3	0
82	3	3.5336906	1.4807182	2.4507662	2.0313735	12.0552355	3561.4	37.61	10316.1	0.011802	0.	3	0
82	4	3.7559823	1.4093249	2.5011904	2.0574723	10.9219494	3506.4	34.15	10446.8	0.010882	0.	3	0
82	5	3.9716523	1.3315442	2.5511274	2.0821797	9.7528074	3453.1	31.25	10574.1	0.010114	-0.0000000	3	0
82	6	4.2086419	1.2637479	2.6214493	2.1164904	9.1764731	3378.6	27.39	10747.7	0.009058	0.0000000	3	0
82	7	4.4200760	1.1752216	2.6696421	2.1392506	7.9650787	3328.4	25.05	10863.6	0.008411	-0.0000000	3	0
82	8	4.6280571	1.0801715	2.7165799	2.1610599	6.7215616	3279.9	22.91	10973.7	0.007806	0.0000001	2	0
82	9	4.8332213	0.9784178	2.7629429	2.1819540	5.4428941	3232.7	21.04	11080.5	0.007273	-0.0000000	3	0
82	10	5.0866114	0.8934741	2.8332231	2.2129382	4.7891222	3162.2	18.43	11237.8	0.006511	0.0000001	2	0
82	11	5.2953963	0.7191576	2.8777874	2.2320981	3.4919161	3118.1	16.93	11334.7	0.006067	0.0000000	2	0
82	12	5.5030367	0.6575238	2.9196497	2.2497064	2.1768021	3077.3	15.63	11424.0	0.005677	-0.0000000	3	0
82	13	5.7732998	0.5533746	2.9808073	2.2747869	1.5734648	3018.5	13.93	11551.3	0.005156	-0.0000000	3	0
82	14	5.9554826	0.4308424	2.9875340	2.2775455	1.1483062	3012.0	13.74	11564.9	0.005097	-0.0000000	2	0
82	15	5.9322209	0.3746857	2.9803444	2.2745970	0.9214135	3018.9	13.94	11550.3	0.005160	-0.0000000	2	0
82	16	6.1243197	0.2849088	2.9951252	2.2806586	1.5208541	3004.7	13.53	11580.3	0.005031	-0.0000000	3	0
82	17	6.0714442	0.2390893	2.9974450	2.2816099	1.1439113	3002.5	13.46	11584.9	0.005011	0.0000000	2	0
82	18	6.2068526	0.1296485	3.0353238	2.2964737	-0.0234727	2967.0	12.57	11661.9	0.004736	-0.0000000	5	0
83	1	3.2738056	1.7770546	2.3652743	1.9862361	14.0369749	3655.4	43.96	10086.7	0.013439	0.0000001	3	0
83	2	3.3173308	1.5564800	2.4008860	2.0055287	13.2167464	3615.8	41.05	10183.0	0.012688	-0.0000000	3	0
83	3	3.5518593	1.4938447	2.4550349	2.0335853	12.1216981	3556.7	37.32	10327.3	0.011725	-0.0000000	3	0
83	4	3.7815559	1.4269046	2.5071610	2.0604264	11.0154105	3500.0	33.80	10462.2	0.010792	0.0000000	3	0
83	5	4.0041240	1.3525141	2.5580977	2.0856284	9.8656489	3445.7	30.85	10591.5	0.010005	0.	3	0
83	6	4.2208943	1.2712327	2.6066187	2.1094862	8.6792443	3394.1	28.10	10711.3	0.009253	0.	3	0
83	7	4.4666776	1.2017750	2.6782823	2.1433312	8.1020135	3319.3	24.63	10884.0	0.008293	0.0000001	2	0
83	8	4.6807052	1.1085862	2.7260453	2.1653256	6.8713018	3270.2	22.53	10995.8	0.007699	0.0000001	2	0
83	9	4.8925688	1.0082724	2.7726668	2.1863362	5.6062956	3222.8	20.65	11102.5	0.007159	-0.0000000	3	0
83	10	5.1019316	0.9007075	2.8178000	2.2063072	4.3043897	3177.5	18.94	11203.5	0.006662	0.0000000	2	0
83	11	5.3683326	0.8114449	2.8879759	2.2364785	3.6711424	3108.0	16.59	11356.4	0.005963	0.0000001	2	0
83	12	5.5827252	0.6901570	2.9301153	2.2539983	2.3775482	3067.2	15.34	11446.2	0.005589	0.0000000	3	0
83	13	5.7946143	0.5615571	2.9658944	2.2686712	1.1229987	3032.8	14.34	11520.8	0.005285	-0.0000000	3	0
83	14	6.0448286	0.4647344	2.9977544	2.2817368	1.3563246	3002.2	13.45	11585.6	0.005008	-0.0000001	2	0
83	15	6.0223973	0.4085733	2.9903995	2.2787206	1.1290878	3009.2	13.66	11570.7	0.005072	-0.0000000	2	0
83	16	6.1594283	0.2982861	2.9826505	2.2755428	1.1017844	3016.7	13.88	11555.0	0.005140	0.0000000	3	0
83	17	6.1611184	0.2728975	3.0067408	2.2852942	1.2557755	2993.7	13.24	11603.9	0.004940	0.0000001	2	0
83	18	6.2992763	0.1619655	3.0414833	2.2988828	0.1381363	2961.3	12.43	11674.3	0.004691	-0.0000000	4	0
84	1	3.5363269	1.7251774	2.4223038	2.0166261	12.9999883	3592.4	39.58	10240.6	0.012311	-0.0000001	2	0
84	2	3.5673277	1.5051542	2.4590237	2.0356520	12.1895725	3552.4	37.04	10337.8	0.011653	-0.0000000	3	0
84	3	3.8009218	1.4402313	2.5115515	2.0625987	11.0826037	3495.4	33.55	10473.5	0.010725	0.0000000	3	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
84	4	4.0316784	1.3703377	2.5639674	2.0885325	9.9607761	3439.4	30.51	10606.2	0.009913	0.0000001	2	0
84	5	4.2558298	1.2924434	2.6137979	2.1128768	8.7947869	3386.6	27.76	10728.9	0.009159	0.0000001	2	0
84	6	4.4751e82	1.2070005	2.6626858	2.1359653	7.5880696	3335.6	25.39	10847.0	0.008506	0.0000001	2	0
84	7	4.7300946	1.1353197	2.7349222	2.1693261	7.0130436	3261.2	22.17	11016.4	0.007597	0.0000001	2	0
84	8	4.9490622	1.0367954	2.7819346	2.1905129	5.7631528	3213.4	20.27	11123.4	0.007050	-0.0000000	3	0
84	9	5.1655945	0.9305831	2.8277637	2.2105910	4.4784045	3167.6	18.61	11225.7	0.006565	0.0000001	2	0
84	10	5.3798671	0.8165166	2.8714265	2.2293633	3.1597694	3124.4	17.14	11321.0	0.006131	-0.0000001	2	0
84	11	5.6607890	0.7223244	2.9405109	2.2582615	2.5755513	3057.2	15.05	11468.0	0.005502	-0.0000001	2	0
84	12	5.8797085	0.5940639	2.9761177	2.2728637	1.3533979	3023.0	14.06	11541.7	0.005197	-0.0000000	3	0
84	13	6.0620775	0.4712356	2.9812166	2.2749523	0.8610616	3018.1	13.92	11552.1	0.005152	-0.0000000	2	0
84	14	6.1123523	0.4426268	3.0008258	2.2829807	1.3383922	2999.2	13.37	11591.8	0.004982	0.0000000	2	0
84	15	6.2509158	0.3329515	2.9937491	2.2800942	1.2998211	3006.0	13.57	11577.5	0.005043	-0.0000000	3	0
84	16	6.1960550	0.2859697	2.9934407	2.2799678	0.8310409	3006.3	13.57	11576.9	0.005046	-0.0000000	2	0
84	17	6.3935127	0.1951470	3.0493647	2.3019655	0.3183081	2953.9	12.25	11690.0	0.004634	-0.0000000	4	0
85	1	3.7570179	1.8924577	2.4388327	2.0251903	12.7322112	3574.4	38.44	10284.6	0.012016	0.0000001	3	0
85	2	3.7967638	1.6716637	2.4784034	2.0456933	11.9567560	3531.2	35.71	10388.2	0.011299	-0.0000000	2	0
85	3	3.8176673	1.4517659	2.5156732	2.0646380	11.1513760	3491.0	33.31	10484.1	0.010662	0.0000000	3	0
85	4	4.0525217	1.3838375	2.5682789	2.0906657	10.0291278	3434.8	30.26	10616.9	0.009845	-0.0000000	3	0
85	5	4.2854770	1.3104763	2.6196445	2.1157325	8.8921732	3380.3	27.46	10743.7	0.009079	-0.0000000	3	0
85	6	4.5127559	1.2284078	2.6697428	2.1392982	7.7073106	3328.2	25.05	10863.8	0.008410	0.	3	0
85	7	4.7355542	1.1382551	2.7177506	2.1615875	6.4802596	3278.7	22.86	10976.5	0.007793	0.0000001	2	0
85	8	5.0020775	1.0636567	2.7906373	2.1944349	5.9113476	3204.6	19.92	11142.8	0.006946	0.0000001	2	0
85	9	5.2262204	0.9591571	2.8372756	2.2146805	4.6449363	3158.2	18.29	11246.7	0.006471	0.0000000	2	0
85	10	5.4481773	0.8463594	2.8811693	2.2335521	3.3484734	3114.8	16.81	11341.9	0.006032	-0.0000000	2	0
85	11	5.6677589	0.7251761	2.9216324	2.2506015	2.0309999	3075.2	15.57	11428.6	0.005659	-0.0000001	3	0
85	12	5.9630579	0.6261663	2.9863180	2.2770468	1.5774399	3013.2	13.77	11562.5	0.005108	0.0000000	3	0
85	13	6.1503201	0.5043112	2.9919205	2.2793443	1.1085844	3007.8	13.62	11573.8	0.005059	-0.0000000	2	0
85	14	6.1284944	0.4486966	2.9837760	2.2760043	0.8298510	3015.6	13.84	11557.3	0.005130	-0.0000000	2	0
85	15	6.3422592	0.3677649	3.0053159	2.2847369	1.4993772	2995.0	13.27	11601.0	0.004951	-0.0000000	3	0
85	16	6.2886975	0.3204516	3.0044100	2.2843826	1.0429116	2995.9	13.29	11599.2	0.004957	-0.0000000	2	0
85	17	6.4260470	0.2065244	3.0321040	2.2952144	-0.1693507	2970.0	12.65	11655.5	0.004759	-0.0000000	4	0
86	1	4.0273350	1.8363683	2.4931334	2.0533255	11.6777354	3515.2	34.69	10426.1	0.011028	-0.0000000	2	0
86	2	4.0575747	1.6157997	2.5338920	2.0736521	10.9047116	3471.5	32.25	10530.6	0.010382	-0.0000000	2	0
86	3	4.0706211	1.3955735	2.5723460	2.0926780	10.0991778	3430.5	30.03	10627.0	0.009781	0.0000000	3	0
86	4	4.3078811	1.3241230	2.6242808	2.1178276	8.9621058	3375.6	27.25	10754.0	0.009020	-0.0000000	3	0
86	5	4.5446365	1.2466139	2.6750e80	2.1421060	7.8077283	3322.0	24.76	10877.8	0.008328	0.0000001	2	0
86	6	4.7759330	1.1598167	2.7250210	2.1648640	6.6043432	3271.3	22.57	10993.4	0.007710	-0.0000000	3	0
86	7	5.0032942	1.0642688	2.7725996	2.1863059	5.3568293	3222.9	20.65	11102.4	0.007160	0.0000001	2	0
86	8	5.2831354	0.9860933	2.8462197	2.2185259	4.8018579	3149.3	17.99	11266.3	0.006383	-0.0000000	3	0
86	9	5.5132406	0.8749379	2.8904891	2.2375591	3.5281745	3105.6	16.50	11361.7	0.005938	-0.0000000	2	0
86	10	5.7410516	0.7549582	2.9318e405	2.2547058	2.2402261	3065.5	15.29	11449.8	0.005575	0.0000000	3	0
86	11	5.9645560	0.6267389	2.9660821	2.2687481	0.9899344	3032.6	14.34	11521.2	0.005283	0.0000000	3	0
86	12	6.2367384	0.5369950	3.0027001	2.2837138	1.3461499	2997.5	13.33	11595.6	0.004969	-0.0000000	2	0
86	13	6.2174442	0.4819536	2.9946654	2.2804700	1.0812485	3005.1	13.54	11579.4	0.005035	-0.0000000	2	0
86	14	6.3542534	0.3723213	2.9861510	2.2769783	0.9349505	3013.3	13.78	11562.1	0.005109	0.0000000	3	0
86	15	6.3811767	0.3551224	3.0159935	2.2889132	1.2539406	2985.1	13.02	11622.8	0.004875	0.0000000	2	0
86	16	6.5240547	0.2406606	3.0426890	2.2993544	0.1316348	2960.2	12.40	11676.7	0.004683	0.0000000	4	0
87	1	4.2633698	2.0023724	2.5055348	2.0596218	11.3888755	3501.8	33.89	10458.0	0.010816	0.0000000	3	0
87	2	4.2980948	1.7776645	2.5474868	2.0803784	10.6166540	3457.0	31.47	10564.9	0.010171	-0.0000000	2	0
87	3	4.3211153	1.5568311	2.5885208	2.1006808	9.8408300	3413.2	29.09	10666.9	0.009524	-0.0000000	2	0
87	4	4.3274171	1.3360377	2.6284860	2.1198136	9.0338293	3371.3	27.05	10764.8	0.008965	0.0000001	2	0
87	5	4.5687028	1.2603807	2.6800449	2.1441636	7.8797990	3317.5	24.55	10888.1	0.008269	-0.0000000	3	0
87	6	4.8102003	1.1781599	2.7311473	2.1676249	6.7087495	3265.0	22.32	11007.6	0.007640	-0.0000000	3	0
87	7	5.0466946	1.0859406	2.7797473	2.1895271	5.4872994	3215.7	20.36	11118.4	0.007075	0.0000001	2	0
87	8	5.2794182	0.9843475	2.8263457	2.2099813	4.2216486	3169.0	18.66	11222.5	0.006579	0.0000000	2	0
87	9	5.5743324	0.9019093	2.8992676	2.2413333	3.6967816	3096.9	16.21	11380.3	0.005848	-0.0000000	2	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR
													INDICATOR
87	10	5.8108646	0.7835168	2.9414363	2.2586410	2.4380590	3056.3	15.03	11470.0	0.005494	-0.0000000	2	0
87	11	6.0430316	0.6565140	2.9759696	2.2728029	1.2274723	3023.1	14.06	11541.4	0.005198	-0.0000000	3	0
87	12	6.2326365	0.5354568	2.9805579	2.2746846	0.7089652	3018.7	13.93	11550.8	0.005158	0.0000000	3	0
87	13	6.3045509	0.5148188	3.0057496	2.2849065	1.3216328	2994.6	13.26	11601.9	0.004947	-0.0000000	2	0
87	14	6.4450337	0.4064219	2.9979998	2.2818374	1.1912404	3001.9	13.45	11586.1	0.005006	-0.0000001	2	0
87	15	6.3925340	0.3593458	2.9959425	2.2809937	0.6801266	3003.9	13.50	11581.9	0.005024	-0.0000000	2	0
87	16	6.6216727	0.2750772	3.0537576	2.3036836	0.4076403	2949.8	12.15	11698.7	0.004602	-0.0000001	3	0
88	1	4.5540140	1.9406197	2.5585767	2.0858653	10.3225079	3445.2	30.82	10592.7	0.009998	0.0000000	2	0
88	2	4.5716315	1.7155983	2.6003350	2.1065186	9.5455024	3400.6	28.41	10695.8	0.009335	-0.0000000	2	0
88	3	4.5886361	1.4942107	2.6433091	2.1268142	8.7660941	3355.8	26.33	10800.7	0.008767	-0.0000000	2	0
88	4	4.5897732	1.2724515	2.6841960	2.1461241	7.9536956	3313.2	24.35	10897.9	0.008212	0.0000001	2	0
88	5	4.8360423	1.1920197	2.7356314	2.1696457	6.7836409	3260.5	22.14	11018.0	0.007589	-0.0000000	3	0
88	6	5.0835233	1.1043853	2.7857724	2.1922424	5.5969197	3209.5	20.12	11131.9	0.007004	0.0000000	2	0
88	7	5.3260743	1.0060874	2.8337136	2.2131490	4.3605747	3161.7	18.41	11238.8	0.006507	0.0000001	2	0
88	8	5.5648753	0.8977689	2.8783355	2.2323337	3.0854738	3117.6	16.91	11335.9	0.006061	0.0000000	3	0
88	9	5.8764208	0.8105017	2.9504916	2.2623545	2.6225399	3047.6	14.77	11488.9	0.005417	0.0000000	3	0
88	10	6.1177527	0.6851084	2.9854739	2.2767006	1.4496750	3014.0	13.80	11560.8	0.005115	0.0000000	3	0
88	11	6.3142701	0.5658247	2.9909087	2.2789294	0.9653254	3008.7	13.64	11571.8	0.005068	-0.0000001	2	0
88	12	6.2989797	0.5127351	2.9829566	2.2756683	0.6703107	3016.4	13.87	11555.7	0.005137	0.0000000	1	0
88	13	6.53339266	0.4401114	3.0101315	2.2866204	1.4332261	2990.5	13.16	11610.9	0.004916	-0.0000000	3	0
88	14	6.4844887	0.3933112	3.0079527	2.2857682	0.9489910	2992.6	13.21	11606.4	0.004932	-0.0000001	2	0
88	15	6.6283066	0.2773969	3.0304827	2.2945803	-0.2447890	2971.6	12.69	11652.2	0.004771	-0.0000000	4	0
89	1	4.7949015	2.1059301	2.5896850	2.1012568	10.7174703	3412.0	29.02	10669.7	0.009505	-0.	3	0
89	2	4.8274776	1.8752723	2.6102737	2.1112124	9.2476721	3390.2	27.93	10720.3	0.009205	-0.0000000	2	0
89	3	4.8493014	1.6495939	2.6538079	2.1317725	8.4657204	3344.9	25.82	10825.9	0.008626	-0.0000000	2	0
89	4	4.8618422	1.4272314	2.6968970	2.1521225	7.6788292	3299.9	23.73	10927.5	0.008036	-0.0000000	2	0
89	5	4.8587587	1.2042233	2.7399264	2.1715813	6.8603506	3256.1	21.97	11027.9	0.007540	0.0000001	2	0
89	6	5.1112667	1.1183118	2.7901770	2.1942274	5.6754904	3205.1	19.94	11141.8	0.006952	0.0000001	2	0
89	7	5.3656628	1.0245980	2.8399267	2.2158203	4.4770779	3155.6	18.20	11252.5	0.006445	0.0000000	2	0
89	8	5.6150379	0.9195424	2.8855878	2.2354518	3.2356833	3110.4	16.67	11351.3	0.005988	-0.0000001	2	0
89	9	5.8602868	0.8039205	2.9272981	2.2528430	1.9722788	3069.9	15.42	11440.2	0.005613	-0.0000001	3	0
89	10	6.1878962	0.7121628	2.9944608	2.2803861	1.6550119	3005.3	13.55	11578.9	0.005037	0.0000000	3	0
89	11	6.3919579	0.5949993	3.0008752	2.2830000	1.2024992	2999.2	13.37	11591.9	0.004982	-0.0000001	2	0
89	12	6.3813376	0.5432854	2.9934694	2.2799796	0.9313103	3006.3	13.57	11576.9	0.005045	-0.0000000	2	0
89	13	6.5231490	0.4360671	2.9850717	2.2765357	0.7269823	3014.4	13.81	11560.0	0.005119	-0.0000000	3	0
89	14	6.5745094	0.4268837	3.0200022	2.2904811	1.2012626	2981.3	12.93	11631.0	0.004846	0.0000000	2	0
89	15	6.7257962	0.3112627	3.0424884	2.2992760	0.1007244	2960.3	12.41	11676.3	0.004684	-0.0000001	3	0
90	1	5.0904126	2.0407594	2.6419756	2.1261844	9.6561269	3357.2	26.39	10797.5	0.008785	0.0000000	2	0
90	2	5.1152309	1.8051186	2.6620860	2.1356821	8.1662948	3336.2	25.42	10845.6	0.008514	-0.0000001	2	0
90	3	5.1327298	1.5789641	2.7058028	2.1562030	7.3753676	3290.8	23.35	10948.4	0.007928	-0.0000000	2	0
90	4	5.1418717	1.3552768	2.7509930	2.1765686	6.5812898	3244.9	21.52	11053.3	0.007412	-0.0000000	2	0
90	5	5.1357507	1.1306264	2.7944199	2.1961395	5.7557976	3200.7	19.77	11151.2	0.006901	0.0000001	2	0
90	6	5.3954528	1.0385645	2.8444624	2.2177704	4.5605177	3151.1	18.05	11262.5	0.006400	0.0000000	2	0
90	7	5.6575920	0.9380919	2.8917069	2.2380826	3.3612864	3104.3	16.46	11364.3	0.005925	-0.0000001	2	0
90	8	5.9142115	0.8257113	2.9348012	2.2559200	2.1377321	3062.7	15.21	11456.0	0.005550	0.0000000	3	0
90	9	6.1640916	0.7030734	2.9697900	2.2702687	0.9549187	3029.0	14.23	11528.8	0.005251	0.0000000	3	0
90	10	6.4648700	0.6226137	3.0106937	2.2868403	1.4196984	2990.0	13.14	11612.0	0.004912	-0.0000000	2	0
90	11	6.4597034	0.5726358	3.0037122	2.2841096	1.1720018	2996.5	13.31	11597.7	0.004962	-0.0000000	2	0
90	12	6.6075052	0.4674342	2.9964076	2.2811845	0.9992213	3003.5	13.49	11582.9	0.005020	0.0000001	2	0
90	13	6.5626637	0.4225097	2.9941520	2.2802595	0.4827759	3005.6	13.55	11578.3	0.005039	-0.0000000	2	0
90	14	6.8209982	0.3447983	3.0544116	2.3039395	0.4101030	2949.2	12.13	11700.0	0.004597	0.0000000	3	0
91	1	5.3551385	2.2022181	2.6501693	2.1300541	9.3919352	3348.7	25.99	10817.2	0.008675	0.0000000	3	0
91	2	5.3981634	1.9711197	2.6929185	2.1502435	8.5915526	3304.1	23.92	10918.3	0.008092	0.0000000	2	0
91	3	5.4088120	1.7312848	2.7127451	2.1593317	7.0763718	3283.7	23.07	10964.7	0.007850	-0.0000000	2	0
91	4	5.4231515	1.5030555	2.7580867	2.1797655	6.2774330	3237.7	21.24	11069.5	0.007329	-0.0000000	2	0
91	5	5.4299924	1.2776480	2.8033589	2.2000984	5.4756618	3191.7	19.43	11171.1	0.006802	-0.0000000	2	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
91	6	5.4218471	1.0509674	2.8488585	2.2196605	4.6455175	3146.7	17.90	11272.1	0.006357	0.0000000	2	0
91	7	5.6895744	0.9520790	2.8961679	2.2400006	3.4511308	3099.9	16.31	11373.8	0.005880	-0.0000000	2	0
91	8	5.9599422	0.8442664	2.6411361	2.2585179	2.2755307	3056.6	15.03	11469.3	0.005496	0.0000000	3	0
91	9	6.2219219	0.7249251	2.9772551	2.2733301	1.1406694	3021.9	14.03	11544.1	0.005187	0.0000000	3	0
91	10	6.4340609	0.6110732	2.9837388	2.2759891	0.6681155	3015.6	13.84	11557.3	0.005130	-0.0000000	3	0
91	11	6.5332475	0.6004181	3.0136646	2.2880023	1.3918478	2987.2	13.08	11618.1	0.004891	0.0000001	1	0
91	12	6.6877316	0.4975593	3.0075461	2.2856092	1.2472247	2993.0	13.22	11605.6	0.004935	0.0000001	2	0
91	13	6.64461251	0.4537783	3.0056130	2.2848531	0.7660185	2994.8	13.26	11601.0	0.004948	0.0000000	2	0
91	14	6.8023071	0.3382850	3.0255129	2.2926365	-0.3989431	2976.2	12.80	11642.2	0.004806	-0.0000000	4	0
92	1	5.6693342	2.1291321	2.6997804	2.1534842	8.3281299	3296.9	23.59	10934.2	0.007996	-0.0000000	2	0
92	2	5.7090154	1.8963279	2.7441576	2.1734861	7.5224422	3251.8	21.80	11037.7	0.007491	0.0000000	2	0
92	3	5.7095382	1.6512939	2.7632874	2.1821092	5.9813967	3232.4	21.03	11081.3	0.007269	-0.0000000	2	0
92	4	5.7216953	1.4212025	2.8087102	2.2023991	5.1743131	3186.5	19.25	11183.2	0.006751	0.0000000	2	0
92	5	5.7273527	1.1936315	2.8565104	2.2225634	4.3686451	3140.1	17.67	11286.8	0.006290	0.0000000	2	0
92	6	5.7180220	0.9645547	2.9005455	2.2418719	3.5422099	3095.6	16.17	11383.0	0.005836	-0.0000000	2	0
92	7	5.9942675	0.8582842	2.9457479	2.2604091	2.3739237	3052.2	14.90	11479.0	0.005457	0.0000000	3	0
92	8	6.2709342	0.7435647	2.9835529	2.2759169	1.2944642	3015.8	13.85	11556.9	0.005132	0.0000000	3	0
92	9	6.4943260	0.6333937	2.9915325	2.2791852	0.8679999	3008.1	13.63	11573.0	0.005062	-0.0000001	2	0
92	10	6.5006472	0.5882410	2.9860625	2.2769420	0.6260969	3013.4	13.78	11562.0	0.005110	-0.0000000	2	0
92	11	6.7629967	0.5266063	3.0181505	2.2897568	1.4716303	2983.1	12.97	11627.2	0.004859	0.0000001	2	0
92	12	6.7293830	0.4838211	3.0168099	2.2892325	1.0229848	2984.3	13.00	11624.5	0.004869	-0.0000000	2	0
92	13	6.8930323	0.3695900	3.0372601	2.2972311	-0.0497281	2965.2	12.53	11665.8	0.004722	-0.0000000	3	0
93	1	5.9520597	2.2918805	2.7073183	2.1508860	8.1074761	3289.3	23.29	10952.0	0.007911	0.0000000	3	0
93	2	5.9904053	2.0560389	2.7499014	2.1701037	7.2614985	3245.9	21.56	11051.0	0.007424	-0.0000000	2	0
93	3	6.0279365	1.8157103	2.7938127	2.1958659	6.4529128	3201.4	19.79	11149.0	0.006909	-0.0000000	2	0
93	4	6.0184209	1.5651070	2.8123135	2.2039493	4.8841000	3182.9	19.13	11191.3	0.006716	0.0000000	2	0
93	5	6.0295514	1.3326791	2.8356290	2.2239471	4.0736285	3136.9	17.57	11293.3	0.006257	0.0000000	2	0
93	6	6.0346591	1.1020231	2.9049064	2.2436849	3.2737015	3091.4	16.04	11392.0	0.005799	-0.0000000	2	0
93	7	6.0249184	0.8708253	2.9502792	2.2622674	2.4730229	3047.8	14.78	11488.4	0.005419	-0.0000000	3	0
93	8	6.3076661	0.7576034	2.9881485	2.2777975	1.4039434	3011.4	13.72	11566.2	0.005092	-0.0000000	3	0
93	9	6.5455560	0.6524326	2.9981079	2.2818818	1.0324041	3001.8	13.44	11586.3	0.005005	-0.0000000	2	0
93	10	6.5614756	0.6107020	2.9934966	2.2801835	0.8295273	3005.8	13.56	11577.4	0.005041	0.0000000	1	0
93	11	6.7243006	0.5115880	2.9852325	2.2778565	0.6540287	3011.3	13.72	11566.5	0.005091	-0.0000000	2	0
93	12	6.8055992	0.5122601	3.0273193	2.2933429	1.2547145	2974.5	12.76	11645.8	0.004794	0.0000000	2	0
93	13	6.9790969	0.3997136	3.0464951	2.3016254	0.2574026	2954.7	12.27	11688.3	0.004640	-0.0000000	3	0
94	1	6.2640132	2.2097380	2.7562518	2.1789365	7.0458102	3239.5	21.31	11065.3	0.007351	-0.0000000	2	0
94	2	6.3195567	1.9661081	2.7982320	2.1978575	6.1959895	3196.9	19.61	11159.0	0.006856	0.0000000	2	0
94	3	6.3560296	1.7206455	2.8433879	2.2173084	5.3868632	3152.1	18.08	11260.1	0.006411	-0.0000000	2	0
94	4	6.3366624	1.4720015	2.8605460	2.2246853	3.7928141	3135.2	17.51	11297.5	0.006240	-0.0000000	2	0
94	5	6.3471574	1.23069681	2.9060434	2.2441265	2.9895343	3090.3	16.01	11394.9	0.005790	0.0000000	2	0
94	6	6.3523603	1.0044143	2.9519592	2.2629564	2.2192533	3046.2	14.73	11491.4	0.005404	0.0000000	2	0
94	7	6.3405892	0.7702379	2.9926670	2.2796587	1.5132711	3007.0	13.60	11575.4	0.005052	0.0000000	3	0
94	8	6.5835661	0.6667592	3.0030176	2.2838380	1.1486382	2997.2	13.32	11596.3	0.004967	-0.0000001	2	0
94	9	6.6129825	0.6295597	3.0006623	2.2829168	0.9965279	2999.4	13.38	11591.4	0.004983	-0.0000000	1	0
94	10	6.7867270	0.5346587	2.9967355	2.2813189	0.8672493	3003.1	13.48	11583.5	0.005017	0.0000000	2	0
94	11	6.7654059	0.4974476	2.9967664	2.2813316	0.4231330	3003.1	13.48	11583.6	0.005017	-0.0000000	2	0
94	12	7.0596809	0.4252614	3.0590594	2.3057575	0.5277341	2944.9	12.03	11709.2	0.004563	-0.0000000	3	0
95	1	6.5903387	2.3740244	2.7631620	2.1820528	6.8741170	3232.5	21.03	11081.3	0.007270	-0.0000001	2	0
95	2	6.6240967	2.1213457	2.8034262	2.2001213	5.9869400	3191.7	19.43	11171.3	0.006802	0.0000000	2	0
95	3	6.6579759	1.8748755	2.8465600	2.2186722	5.1360111	3149.0	17.96	11267.1	0.006380	0.0000000	2	0
95	4	6.6944995	1.6344284	2.8907113	2.2376546	4.3338335	3105.3	16.49	11362.2	0.005935	-0.0000000	2	0
95	5	6.6644447	1.3715466	2.9056192	2.2440346	2.7223479	3090.5	16.02	11394.4	0.005792	-0.0000000	2	0
95	6	6.6747518	1.1336832	2.9506821	2.2624327	1.9512396	3047.4	14.77	11489.3	0.005415	-0.0000000	2	0
95	7	6.6774914	0.8990271	2.9916487	2.2792329	1.2791653	3008.0	13.62	11573.3	0.005061	-0.0000000	2	0
95	8	6.6179184	0.6796995	3.0079772	2.2857778	1.2648309	2992.6	13.21	11606.5	0.004932	-0.0000000	2	0
95	9	6.6515200	0.6442723	3.0057285	2.2848983	1.1146181	2994.7	13.26	11601.9	0.004948	-0.0000001	1	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
95	10	6.8395528	0.5543284	3.0040158	2.2842284	1.0409553	2996.3	13.30	11598.3	0.004960	0.0000001	2	0
95	11	6.8286471	0.5204623	3.0053886	2.2847653	0.6435878	2995.0	13.27	11601.2	0.004950	-0.0000000	2	0
95	12	7.0106909	0.4111488	3.0259390	2.2928031	-0.3980157	2975.8	12.79	11643.0	0.004803	-0.0000000	4	0
96	1	6.9420925	2.2818380	2.8094726	2.2027269	5.8239306	3185.7	19.22	11184.9	0.006743	-0.0000000	2	0
96	2	6.9735994	2.0260156	2.8505185	2.2203741	4.9357514	3145.1	17.84	11275.7	0.006340	-0.0000000	2	0
96	3	7.0066410	1.7763199	2.8924092	2.2383846	4.091262	3103.7	16.44	11365.8	0.005918	0.0000000	2	0
96	4	7.0434412	1.5327020	2.9365197	2.2566247	3.3102610	3061.0	15.16	11459.6	0.005535	-0.0000000	2	0
96	5	7.0017805	1.2634609	2.9483962	2.2614952	1.7024769	3049.6	14.83	11484.5	0.005435	0.0000000	2	0
96	6	7.0084143	1.0240411	2.9880562	2.2777596	1.0311801	3011.5	13.72	11566.0	0.005093	0.0000000	2	0
96	7	6.9562779	0.8066370	3.0055995	2.2848478	1.0117322	2994.8	13.26	11601.6	0.004949	0.0000000	2	0
96	8	6.6862035	0.6573015	3.0107533	2.2868636	1.2321898	2990.0	13.14	11612.2	0.004912	-0.0000000	1	0
96	9	6.8790321	0.5691112	3.0093932	2.2863316	1.1629926	2991.2	13.17	11609.4	0.004922	-0.0000000	3	0
96	10	6.8821530	0.5400886	3.0127706	2.2876526	0.8222845	2988.1	13.10	11616.3	0.004898	0.0000000	2	0
96	11	7.0778098	0.4342618	3.0347914	2.2962655	-0.1356434	2967.5	12.59	11660.9	0.004740	-0.0000000	3	0
97	1	7.2730572	2.4475023	2.8164662	2.2057337	5.7086406	3178.8	18.99	11200.5	0.006675	-0.	2	0
97	2	7.3034497	2.1824892	2.8553632	2.2224571	4.7835811	3140.3	17.68	11286.3	0.006292	-0.0000000	2	0
97	3	7.3332545	1.9231985	2.8950381	2.2395148	3.9018824	3101.1	16.35	11371.4	0.005891	0.0000000	2	0
97	4	7.3655569	1.6701175	2.9367396	2.2567149	3.0781150	3060.8	15.16	11460.1	0.005533	0.0000000	2	0
97	5	7.4025681	1.4233427	2.9782471	2.2737370	2.3474403	3020.9	14.00	11546.1	0.005178	-0.0000000	2	0
97	6	7.3438185	1.1493411	2.9837621	2.2759986	0.8042795	3015.6	13.84	11557.3	0.005130	-0.0000000	2	0
97	7	7.2884201	0.9297173	3.0007026	2.2829325	0.7540314	2999.3	13.37	11591.5	0.004983	0.0000000	2	0
97	8	7.0245657	0.7838765	3.0081066	2.2858284	0.9718593	2992.4	13.20	11606.7	0.004931	0.0000000	3	0
97	9	6.9146559	0.5825112	3.0147208	2.2884154	1.2844543	2986.3	13.05	11620.3	0.004884	0.0000000	2	0
97	10	6.9221286	0.5548390	3.0181066	2.2897396	0.9486229	2983.1	12.97	11627.1	0.004860	-0.0000000	1	0
97	11	7.1345029	0.4539868	3.0422429	2.2991800	0.0743755	2960.6	12.41	11675.8	0.004686	-0.0000000	3	0
98	1	7.6470568	2.3442572	2.8612652	2.2249946	4.6807256	3134.5	17.48	11299.1	0.006233	0.0000000	2	0
98	2	7.6749007	2.0754988	2.8986769	2.2410793	3.7628459	3097.5	16.23	11379.1	0.005854	0.0000000	2	0
98	3	7.7029936	1.8126129	2.9380937	2.2572702	2.9024536	3059.5	15.12	11463.0	0.005522	-0.0000000	2	0
98	4	7.7339805	1.5563117	2.9769105	2.2731888	2.1279376	3022.2	14.04	11543.3	0.005190	0.0000000	2	0
98	5	7.7658582	1.3083202	3.0136099	2.2879809	1.5156071	2987.3	13.08	11618.0	0.004892	-0.0000001	2	0
98	6	7.6252123	1.0531213	2.9954554	2.2807940	0.5240845	3004.4	13.52	11580.9	0.005028	-0.0000000	2	0
98	7	7.3566977	0.9065710	3.0029720	2.2838201	0.7101249	2997.2	13.32	11596.2	0.004967	-0.0000000	3	0
98	8	7.2510751	0.7084009	3.0115074	2.2871585	0.9813283	2989.3	13.13	11613.7	0.004907	0.0000001	2	0
98	9	6.9582162	0.5682191	3.0234051	2.2918120	1.0734520	2978.2	12.85	11637.9	0.004822	-0.0000000	1	0
98	10	7.1767694	0.4688049	3.0476207	2.3012833	0.2204059	2955.6	12.29	11686.5	0.004647	-0.0000000	3	0
99	1	8.0040213	2.5113221	2.8679930	2.2278874	4.6170393	3127.8	17.26	11313.6	0.006165	0.0000000	2	0
99	2	8.0311408	2.2332260	2.9036544	2.2431468	3.6746987	3092.6	16.08	11389.7	0.005810	-0.0000000	2	0
99	3	8.0563142	1.9606309	2.9406417	2.2583151	2.7791481	3057.1	15.05	11468.3	0.005500	0.0000000	2	0
99	4	8.0815976	1.69444809	2.9768758	2.2731746	1.9681301	3022.2	14.04	11543.3	0.005190	0.0000000	2	0
99	5	8.1050822	1.4371929	3.0106652	2.2868291	1.3090717	2990.0	13.14	11612.0	0.004913	0.0000000	2	0
99	6	8.0587599	1.2134708	3.0263654	2.2929699	1.2724700	2975.4	12.78	11643.9	0.004800	0.0000000	3	0
99	7	7.6935446	1.0296004	2.9974288	2.2816033	0.4782593	3002.5	13.46	11584.9	0.005011	0.0000001	2	0
99	8	7.5815027	0.8303063	3.0058488	2.2849453	0.6941294	2994.5	13.26	11602.1	0.004947	0.0000001	2	0
99	9	7.2967253	0.6931388	3.0193929	2.2902428	0.7817298	2981.9	12.94	11629.8	0.004850	-0.0000000	3	0
99	10	7.2150204	0.4822972	3.0530013	2.3033878	0.3632043	2950.5	12.17	11697.2	0.004607	0.0000000	3	0
100	1	8.4014713	2.3963586	2.9096616	2.2456103	3.6266068	3086.9	15.91	11402.6	0.005760	0.0000000	2	0
100	2	8.4250996	2.1142218	2.9445398	2.2599137	2.7082617	3053.3	14.94	11476.5	0.005467	0.0000000	2	0
100	3	8.4459628	1.8382999	2.9781778	2.2737085	1.8628576	3021.0	14.00	11545.9	0.005179	0.0000000	2	0
100	4	8.4614083	1.5714224	3.0092695	2.2862832	1.1657454	2991.3	13.18	11609.1	0.004922	0.0000000	2	0
100	5	8.3992862	1.3406083	3.0227245	2.2915458	1.0604118	2978.8	12.87	11636.5	0.004826	0.0000000	2	0
100	6	8.1296172	1.1904019	3.0286221	2.2938525	1.2351162	2973.3	12.73	11648.5	0.004784	0.0000000	3	0
100	7	7.9170138	0.9525752	2.9997610	2.2825597	0.4471753	3000.2	13.40	11589.6	0.004990	-0.0000000	2	0
100	8	7.6290250	0.8141207	3.0131061	2.2877838	0.5043517	2987.8	13.09	11617.0	0.004895	-0.0000000	3	0
100	9	7.5597438	0.6035417	3.0457536	3.3005531	0.1046625	2957.3	12.33	11682.8	0.004660	-0.0000000	2	0
101	1	8.7875048	2.5643372	2.8990554	2.2412420	3.1247153	3097.1	16.21	11379.9	0.005850	-0.	3	0
101	2	8.8087060	2.2733445	2.9495072	2.2619509	2.6781771	3048.5	14.80	11486.8	0.005425	-0.0000000	2	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
101	3	8.8266641	1.9870583	2.9809608	2.2748498	1.8114851	3018.3	13.92	11551.6	0.005155	0.0000000	2	0
101	4	8.6353405	1.7114590	3.0094309	2.2863463	1.0792085	2991.2	13.17	11609.4	0.004921	-0.0000000	2	0
101	5	8.7576650	1.4732757	3.0207593	2.2907772	0.9163018	2980.6	12.91	11632.5	0.004841	-0.0000000	2	0
101	6	8.4701905	1.3171981	3.0248384	2.2923726	1.0207524	2976.8	12.82	11640.8	0.004811	0.0000001	2	0
101	7	8.3597082	1.1154694	3.0320379	2.2951885	1.2249406	2970.1	12.65	11655.3	0.004760	-0.0000000	3	0
101	8	7.9663406	0.9355005	3.0064883	2.2851954	0.2664801	2993.9	13.24	11603.4	0.004942	0.0000000	3	0
101	9	7.8975255	0.7210251	3.0369381	2.2971051	-0.1407494	2965.5	12.54	11665.2	0.004724	-0.0000000	2	0
102	1	9.2019484	2.4345517	2.9374425	2.2570031	2.1813578	3060.1	15.14	11461.6	0.005528	-0.0000000	2	0
102	2	9.2229044	2.1430922	2.9849224	2.2764744	1.8014999	3014.5	13.81	11559.7	0.005120	-0.0000000	2	0
102	3	9.2264675	1.8574242	3.0112864	2.2870721	1.0480057	2989.5	13.13	11613.2	0.004908	-0.0000000	2	0
102	4	9.1343209	1.6119127	3.0204527	2.2906573	0.8321512	2980.9	12.92	11631.9	0.004843	0.0000000	1	0
102	5	8.8258051	1.4495696	3.0227613	2.2915602	0.8756672	2978.8	12.86	11636.6	0.004826	0.0000001	2	0
102	6	8.6990603	1.2415609	3.0279403	2.2935859	0.996912	2973.9	12.74	11647.1	0.004789	-0.0000000	2	0
102	7	8.4131593	1.0960066	3.0365258	2.2977261	1.0626285	2964.0	12.50	11668.4	0.004713	0.0000000	3	0
102	8	8.2402008	0.8390845	3.0282705	2.2937150	-0.3466007	2973.6	12.74	11647.7	0.004787	0.0000000	2	0
103	1	9.6221070	2.6051105	2.9445127	2.2599026	2.2491980	3053.3	14.94	11476.4	0.005468	0.0000000	2	0
103	2	9.6220720	2.2971243	2.9714512	2.2709500	1.3098130	3027.4	14.19	11532.2	0.005237	-0.0000000	2	0
103	3	9.6238259	2.0092261	3.0144944	2.2883268	1.0586081	2986.5	13.06	11619.0	0.004885	0.0000000	2	0
103	4	9.5288154	1.7566524	3.0214285	2.2912345	0.8055219	2979.5	12.88	11634.9	0.004832	-0.0000000	2	0
103	5	9.2056616	1.5679532	3.0223668	2.2914059	0.7914285	2979.1	12.67	11635.8	0.004829	0.0000000	2	0
103	6	9.0571498	1.3733902	3.0256459	2.2926885	0.8436488	2976.1	12.80	11642.4	0.004806	0.0000000	2	0
103	7	8.7541031	1.2233164	3.0340842	2.2959889	0.8395439	2968.2	12.60	11659.5	0.004745	0.0000000	2	0
103	8	8.7044421	1.0014158	3.0600331	2.3061382	0.5351166	2944.0	12.00	11711.1	0.004556	-0.0000000	3	0
104	1	10.0567638	2.4645953	2.9776650	2.2735067	1.4013111	3021.5	14.01	11544.9	0.005183	-0.0000000	2	0
104	2	10.0369095	2.1578574	2.9990206	2.2822561	0.5707065	3000.9	13.42	11588.1	0.004997	0.0000000	2	0
104	3	9.9400349	1.9073682	3.0248225	2.2936664	0.8218451	2976.8	12.82	11640.0	0.004811	-0.0000000	2	0
104	4	9.6009129	1.7324229	3.0237753	2.2919568	0.7653149	2977.8	12.84	11638.7	0.004819	0.0000001	2	0
104	5	9.4342041	1.5113769	3.0251064	2.2924774	0.7547129	2976.6	12.81	11641.3	0.004809	-0.0000000	2	0
104	6	9.1136627	1.3543935	3.0314903	2.2949744	0.6915211	2970.6	12.66	11654.2	0.004763	0.0000001	2	0
104	7	9.0497406	1.1238456	3.0542694	2.3038838	0.3240146	2949.4	12.14	11699.7	0.004598	0.0000000	2	0
105	1	10.4955822	2.6333369	2.9832200	2.2757703	-1.4728777	3016.1	13.86	11556.2	0.005135	-0.	2	0
105	2	10.4845673	2.3215631	3.0047424	2.2845125	0.6864979	2995.6	13.28	11599.8	0.004955	0.0000000	2	0
105	3	10.3415432	2.0529621	3.0085570	2.2860045	0.3271056	2992.0	13.19	11607.7	0.004928	-0.0000000	2	0
105	4	10.0128604	1.8830231	3.0260167	2.2930682	0.7624831	2975.2	12.78	11644.4	0.004799	'0.0000000	2	0
105	5	9.6297622	1.6556656	3.0264291	2.2929948	0.7263700	2975.3	12.78	11644.0	0.004800	0.0000000	2	0
105	6	9.4427907	1.4916565	3.0306884	2.2946607	0.6080836	2971.4	12.68	11652.6	0.004769	0.0000001	2	0
105	7	9.4147032	1.2522392	3.0505665	2.3024355	0.1921416	2952.8	12.22	11692.4	0.004625	-0.0000000	2	0
106	1	10.9358486	2.4872009	3.0096327	2.2865035	0.7793821	2990.8	13.16	11610.3	0.004918	0.0000000	2	0
106	2	10.7943579	2.2158713	3.0141182	2.2881797	0.4528405	2986.8	13.00	11619.6	0.004888	-0.0000001	2	0
106	3	10.4136853	2.0279980	3.0101678	2.2866424	0.2855281	2990.5	13.16	11611.0	0.004916	0.0000000	2	0
106	4	10.2425426	1.8060567	3.0292238	2.2940879	0.7427494	2972.7	12.72	11649.7	0.004780	0.0000000	2	0
106	5	9.8403353	1.63525462	3.0317816	2.2950883	0.5852591	2970.3	12.66	11654.0	0.004761	0.0000000	2	0
106	6	9.7995119	1.3870050	3.0488273	2.3017553	0.1269981	2954.4	12.26	11688.9	0.004638	-0.0000000	2	0
107	1	11.3771936	2.6494671	3.0125366	2.2875611	0.8064048	2988.3	13.10	11615.6	0.004699	-0.	2	0
107	2	11.2504803	2.3806562	3.0190077	2.2900921	0.5539470	2982.3	12.95	11629.0	0.004853	-0.0000000	2	0
107	3	10.6674827	2.1907608	3.0157208	2.2888065	0.4132339	2985.3	13.03	11622.3	0.004877	-0.0000001	2	0
107	4	10.6402223	1.9493979	3.0123591	2.2874916	0.2355024	2988.5	13.11	11615.4	0.004900	-0.0000000	2	0
107	5	10.3052025	1.7849886	3.0343744	2.2961024	0.6069879	2967.9	12.60	11660.0	0.004743	0.0000000	2	0
107	6	10.2036319	1.5282989	3.0491318	2.3018744	0.1234441	2954.2	12.25	11689.5	0.004636	-0.0000000	2	0
108	1	11.6957691	2.5416998	3.0214888	2.2910625	0.5867843	2979.9	12.89	11634.0	0.004835	-0.0000000	2	0
108	2	11.3245128	2.3554482	3.0205816	2.2907077	0.515970	2980.8	12.92	11632.2	0.004842	-0.0000000	2	0
108	3	11.0958719	2.1122608	3.0179139	2.2896663	0.3666164	2983.3	12.98	11626.8	0.004861	-0.0000000	2	0
108	4	10.7036777	1.9272962	3.0172396	2.2894005	0.1014936	2983.9	12.99	11625.4	0.004866	0.0000001	2	0
108	5	10.6255679	1.6759159	3.0510531	2.3026259	0.1642341	2952.4	12.21	11693.3	0.004622	0.0000000	2	0
109	1	12.0066340	2.6545082	3.0111314	2.2870115	0.2797507	2989.6	13.13	11612.9	0.004909	-0.0000001	2	0
109	2	11.7705045	2.5165249	3.0230260	2.2916638	0.5497596	2978.5	12.86	11637.1	0.004824	0.0000000	1	0

I	J	X (IN.)	Y (IN.)	M	M*	THETA (DEG)	T (DEG R)	P (PSIA)	V (FT/SEC)	DENSITY (LB/CU-FT)	TOLERANCE	ITERATION	ERROR INDICATOR
109	3	11.5545416	2.2769959	3.0227823	2.2915664	0.4716552	2978.7	12.86	11636.6	0.004826	-0.0000000	2	0
109	4	11.1617198	2.0895652	3.0226309	2.2915092	0.2384074	2978.9	12.87	11636.3	0.004827	-0.0000000	2	0
109	5	11.0246063	1.8141311	3.0328014	2.2954871	-0.3403936	2969.4	12.63	11656.9	0.004754	0.0000001	2	0
110	1	12.0830058	2.6287100	3.0125868	2.2875807	0.2418109	2988.3	13.10	11615.9	0.004899	0.0000000	2	0
110	2	12.0015888	2.4379396	3.0251957	2.2925124	0.5064068	2976.5	12.81	11641.5	0.004809	-0.0000000	1	0
110	3	11.6226704	2.2536787	3.0273514	2.2933555	0.3484328	2974.5	12.76	11645.9	0.004793	-0.0000001	2	0
110	4	11.4911890	1.9745655	3.0376690	2.2973968	-0.1809739	2964.8	12.52	11666.7	0.004719	-0.0000000	2	0
111	1	12.1573195	2.6552342	3.0140421	2.2881499	0.2797507	2986.9	13.07	11618.9	0.004889	-0.	2	0
111	2	12.3121752	2.5490744	3.0145453	2.2883467	0.1940319	2986.4	13.05	11619.9	0.004685	0.0000000	2	0
111	3	12.0717218	2.4140074	3.0296266	2.2942454	0.3871813	2972.4	12.71	11650.5	0.004777	-0.0000000	2	0
111	4	11.9601579	2.136d646	3.0419517	2.2990661	-0.0521595	2960.9	12.42	11675.2	0.004688	-0.0000000	2	0
112	1	12.3869220	2.5756640	3.0160132	2.2889209	0.2327317	2985.1	13.02	11622.9	0.004874	-0.0000000	1	0
112	2	12.3828449	2.5244307	3.0166369	2.2900253	0.0757664	2932.4	12.96	11628.0	0.004854	0.0000000	2	0
112	3	12.4159852	2.2952481	3.0437790	2.2997608	0.0009301	2959.1	12.38	11678.9	0.004675	-0.0000000	2	0
113	1	12.6130799	2.6561649	3.0114156	2.2871226	0.0996157	2989.3	13.13	11613.5	0.004907	-0.	2	0

PERFORMANCE BY INTEGRATING ALONG NOZZLE CONTOUR AT WALL POINTS

X (IN.)	Y (IN.)	THRUST (LBF.)	SP. IMPULSE (LBF-SEC/LBM)	CF
1.5264932	1.2807687	2745.1506348	323.3385963	1.3869977
1.6013420	1.3035973	2761.5909119	325.2750206	1.3953043
1.6764733	1.3265429	2777.6883850	327.1710663	1.4034376
1.7517895	1.3495206	2793.4789124	329.0309601	1.4114158
1.8271071	1.3723677	2808.8718667	330.8440247	1.4191931
1.9024507	1.3952227	2823.9130554	332.6156578	1.4267928
1.9775825	1.4178751	2838.5537720	334.3401184	1.4341900
2.0522288	1.4401594	2852.7010498	336.0064621	1.4413380
2.1264130	1.4623057	2866.4395752	337.6246605	1.4482794
2.1997617	1.4839856	2879.7113953	339.1878853	1.4549851
2.2718765	1.5050065	2892.4081116	340.6833725	1.4614002
2.3426619	1.5256401	2904.5851440	342.1176491	1.4675526
2.4117362	1.5456586	2916.2717590	343.4941635	1.4734574
2.4780234	1.5643919	2927.1037903	344.7700157	1.4789303
2.5414870	1.5823272	2937.2677612	345.9671822	1.4840657
2.6013749	1.5992520	2946.6823730	347.0760880	1.4888224
2.6566695	1.6146817	2955.2317200	348.0830765	1.4931420
2.7060167	1.6281320	2962.6668701	348.9588280	1.4968987
2.7481907	1.6396271	2968.9303284	349.6965714	1.5000633
2.7804860	1.6484297	2973.6709595	350.2549477	1.5024585
2.8080094	1.6559316	2977.6715393	350.7261581	1.5044798
3.2738056	1.7770546	3039.6430054	358.0254898	1.5357911
3.7570179	1.8924577	3094.4129639	364.4765892	1.5634639
4.2633698	2.0023724	3143.0234375	370.2021942	1.5880245
4.7949015	2.1059301	3185.0427246	375.1514511	1.6092549
5.3551385	2.2022181	3220.8711973	379.3722267	1.6273604
5.9520597	2.2918806	3252.0583191	383.0449066	1.6431148
6.5903387	2.3740244	3278.7306519	386.1865196	1.6565911
7.2730572	2.4475023	3300.9951477	388.8089523	1.6678403
8.0040213	2.5113221	3319.0097046	390.9308014	1.6769422
8.7875048	2.5643372	3333.1553650	392.5969543	1.6840894
9.6221070	2.6051056	3343.4672241	393.8115387	1.6892995
10.4955822	2.6333969	3350.1710510	394.6011543	1.6926866
11.3771936	2.6494871	3353.7707825	395.0251503	1.6945054
12.0086340	2.6545082	3354.8682556	395.1544151	1.6950599
12.1573195	2.6552342	3355.0268555	395.1730957	1.6951400
12.4244112	2.6551836	3355.1458435	395.1871109	1.6952001

MASS FLOW RATE BY INTEGRATING ALONG THE STARTING LINE

FLOW RATE = 8.4900184 LBM/SLC

***** END OF CASE *****

APPENDIX A
THE CHARACTERISTIC UNIT PROCESSES

CASE 1, Calculation of a General Field Point

Given the flow properties at points r and ℓ , the properties at point n are to be determined. This unit process is illustrated in FIG A-1. In FIG A-1, i refers to the iteration.

The flow properties at point n are calculated by the following relations:

1. Obtain M_ℓ^* and M_r^* from the thermodynamic table (M_ℓ and M_r as inputs)
2. $\alpha_\ell = \sin^{-1} \frac{1}{M_\ell}$
3. $\alpha_r = \sin^{-1} \frac{1}{M_r}$
4. $\lambda_\ell = \tan(\theta_\ell + \alpha_\ell)$
5. $\lambda_r = \tan(\theta_r - \alpha_r)$
6. $H_\ell = \frac{\cot \alpha_\ell}{M_\ell^*}$
7. $H_r = \frac{\cot \alpha_r}{M_r^*}$
8. $\beta_\ell = \frac{\sin \theta_\ell \sin \alpha_\ell}{y_\ell \sin(\theta_\ell + \alpha_\ell)}$
9. $\beta_r = \frac{\sin \theta_r \sin \alpha_r}{y_r \cos(\theta_r - \alpha_r)}$

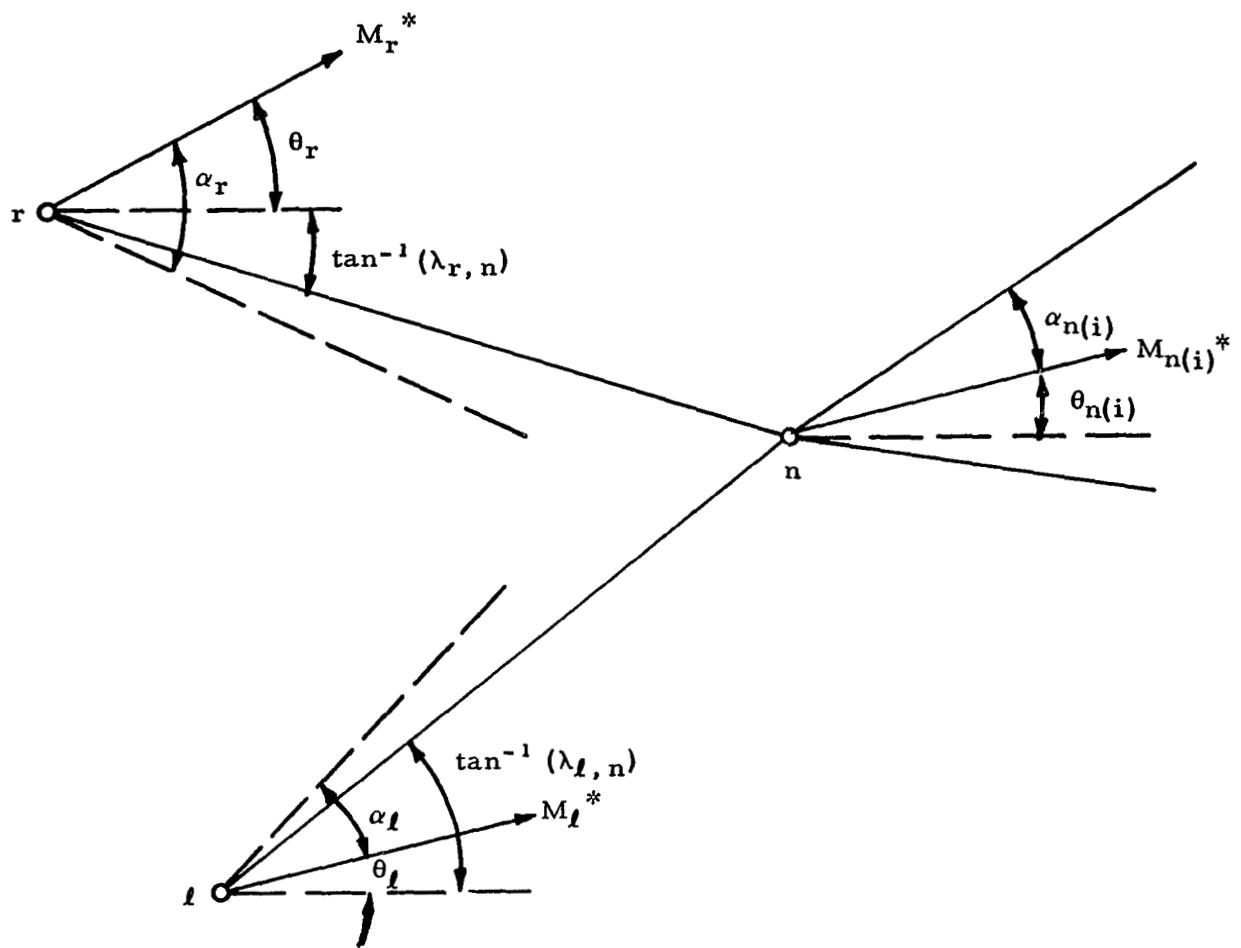


Figure A-1. Field Point Unit Process

$$10. \quad x_n = \frac{(\lambda_r x_r - \lambda_\ell x_\ell) + y_\ell - y_r}{\lambda_r - \lambda_\ell}$$

$$11. \quad y_n = y_\ell - \lambda_\ell (x_\ell - x_n)$$

$$12. \quad M_n^* = \frac{\theta_r - \theta_\ell + H_\ell M_\ell^* + H_r M_r^* - \beta_r (x_r - x_n) - \beta_\ell (y_\ell - y_n)}{H_\ell + H_r}$$

$$13. \quad \theta_n = \theta_\ell - H_\ell (M_\ell^* - M_n^*) + \beta_\ell (y_\ell - y_n)$$

14. Obtain M_n from thermodynamic table (M_n^* as input)

$$15. \quad \alpha_n = \sin^{-1} \frac{1}{M_n}$$

$$16. \quad \lambda_n = \tan (\theta_n + \alpha_n)$$

$$17. \quad \lambda_n' = \tan (\theta_n - \alpha_n)$$

$$18. \quad H_n = \frac{\cot \alpha_n}{M_n^*}$$

$$19. \quad \beta_n = \frac{\sin \theta_n \sin \alpha_n}{y_n \sin (\theta_n + \alpha_n)}$$

$$20. \quad \beta_n' = \frac{\sin \theta_n \sin \alpha_n}{y_n \cos (\theta_n - \alpha_n)}$$

$$21. \quad \lambda_{\ell, n} = \frac{\lambda_\ell + \lambda_n}{2}$$

$$22. \quad \lambda_{r, n} = \frac{\lambda_r + \lambda_n}{2}$$

$$23. \quad H_{\ell, n} = \frac{H_\ell + H_n}{2}$$

$$24. \quad H_{r, n} = \frac{H_r + H_n}{2}$$

$$25. \quad \beta_{\ell, n} = \frac{\beta_\ell + \beta_n}{2}$$

$$26. \quad \beta_{r,n} = \frac{\beta_r + \beta_n}{2}$$

$$27. \quad x_{n(i)} = \frac{\lambda_{r,n} x_r - \lambda_{\ell,n} x_{\ell} + y_{\ell} - y_r}{\lambda_{r,n} - \lambda_{\ell,n}}$$

$$28. \quad y_{n(i)} = y_{\ell} - \lambda_{\ell,n} (x_{\ell} - x_{n(i)})$$

$$29. \quad M_{n(i)}^* = \frac{\theta_r - \theta_{\ell} + H_{\ell,n} M_{\ell}^* + H_{r,n} M_r^* - \beta_{r,n} (x_r - x_{n(i)}) - \beta_{\ell,n} (y_{\ell} - y_{n(i)})}{H_{\ell,n} + H_{r,n}}$$

$$30. \quad \theta_{n(i)} = \theta_{\ell} - H_{\ell,n} (M_{\ell}^* - M_{n(i)}^*) + \beta_{\ell,n} (y_{\ell} - y_{n(i)})$$

31. If either $|\theta_{n(i)} - \theta_n| \leq 10^{-7}$ or the number of iterations exceeds 50, return to the main program; otherwise, set $\theta_n = \theta_{n(i)}$, $M_n^* = M_{n(i)}^*$, $x_n = x_{n(i)}$, and $y_n = y_{n(i)}$, increment the iteration counter by 1 and return to step 14.

CASE 2, Calculation of a Field Point Adjacent to the Axis

Given the flow properties at a point on the axis of symmetry and at the field point adjacent to the axis, a point adjacent to the axis is calculated. The unit process for CASE 2 is the same as the one for CASE 1 except that $\theta_{\ell} = 0$ and $y_{\ell} = 0$ (see Figure A-1). However, because of several indeterminate forms which result for $\theta_{\ell} = 0$ and $y_{\ell} = 0$, formulas 8., 12., 13., and 25. listed under CASE 1 must be replaced by the following relations:

$$8'. \quad \beta_L = 0$$

$$12'. \quad M_n^* = \frac{2\theta_r + H_{\ell} M_{\ell}^* + 2H_r M_r^* + 2\beta_r (x_n - x_r)}{H_{\ell} + 2H_r}$$

$$13'. \quad \theta_n = \frac{H_{\ell} (M_n^* - M_{\ell}^*)}{2}$$

$$25'. \quad \beta_{l,n} = \frac{(\sin \theta_n)/y_n + \beta_n}{2}$$

CASE 3, Calculation of a Point on the Axis of Symmetry

Given the flow properties at point r, the properties at point n ($y_n = 0$, $\theta_n = 0$) are to be determined. This unit process is illustrated in FIG A-2.

The flow properties at point n are calculated by the following relations:

1. Obtain M_r^* from the thermodynamic table using the known value of M_r .
2. $\alpha_r = \sin^{-1} \frac{1}{M_r}$
3. $\lambda_r = \tan (\theta_r - \alpha_r)$
4. $H_r = \frac{\cot \alpha_r}{M_r^*}$
5. $\beta_r = \frac{\sin \theta_r \sin \alpha_r}{y_r \cos (\theta_r - \alpha_r)}$
6. $x_n = x_r - y_r / \lambda_r$
7. $M_n^* = \frac{\theta_r + H_r M_r^* + \beta_r (x_n - x_r)}{H_r}$
8. Obtain M_n from thermodynamic table by entering M_n^*
9. $\alpha_n = \sin^{-1} \frac{1}{M_n}$
10. $\lambda_n = \tan (\theta_n - \alpha_n)$

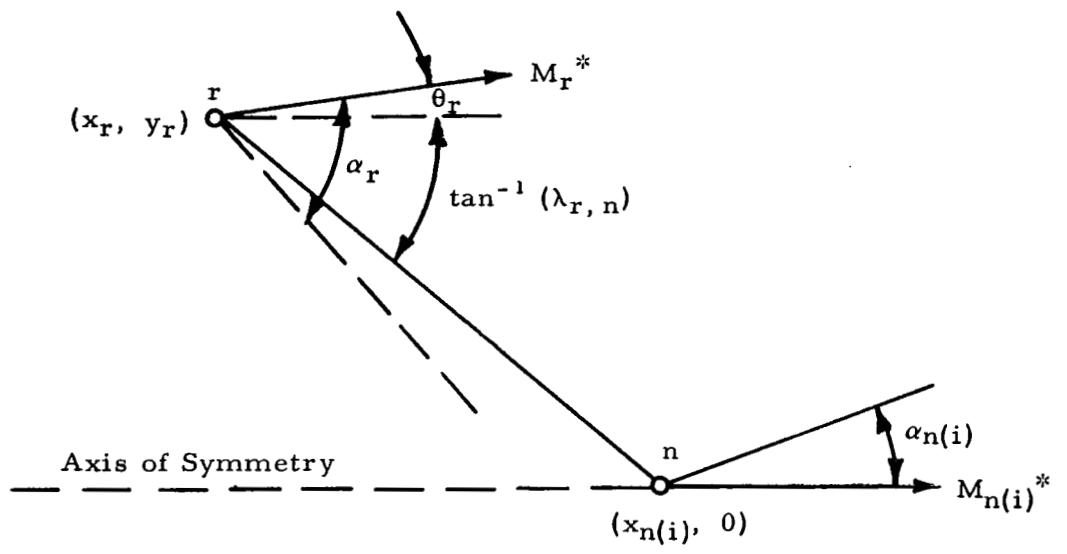


Figure A-2. Unit Process for Point on Axis of Symmetry

$$11. \quad H_n = \frac{\cot \alpha_n}{M_n^*}$$

$$12. \quad \lambda_{r,n} = \frac{\lambda_r + \lambda_n}{2}$$

$$13. \quad H_{r,n} = \frac{H_r + H_n}{2}$$

$$14. \quad \beta_n = \tan \alpha_n \left(\frac{\theta_r}{y_r} \right)$$

$$15. \quad \beta_{r,n} = \frac{\beta_r + \beta_n}{2}$$

$$16. \quad x_{n(i)} = x_r - y_r / \lambda_{r,n}$$

$$17. \quad M_{n(i)}^* = \frac{\theta_r + H_{r,n}}{H_{r,n}} \frac{M_r^* + \beta_{r,n} (x_{n(i)} - x_r)}{M_r^* + \beta_{r,n}}$$

18. If either $|M_{n(i)}^* - M_n^*| \leq 10^{-7}$ or the number of iterations exceeds 50, return to the main program; otherwise, set $x_n = x_{n(i)}$.

$M_n^* = M_{n(i)}^*$, increment the iteration counter by 1 and go to step 8.

CASE 4, Calculation of a Point on the Contour

Given the flow properties at a point ℓ , the properties at point n are to be determined. The unit process for a boundary point is illustrated in FIG A-3.

The properties at point n are determined by the following relations:

1. Obtain M_ℓ^* from the thermodynamic table using M_ℓ as input.

2. $\alpha = \sin^{-1} \frac{1}{M_\ell}$

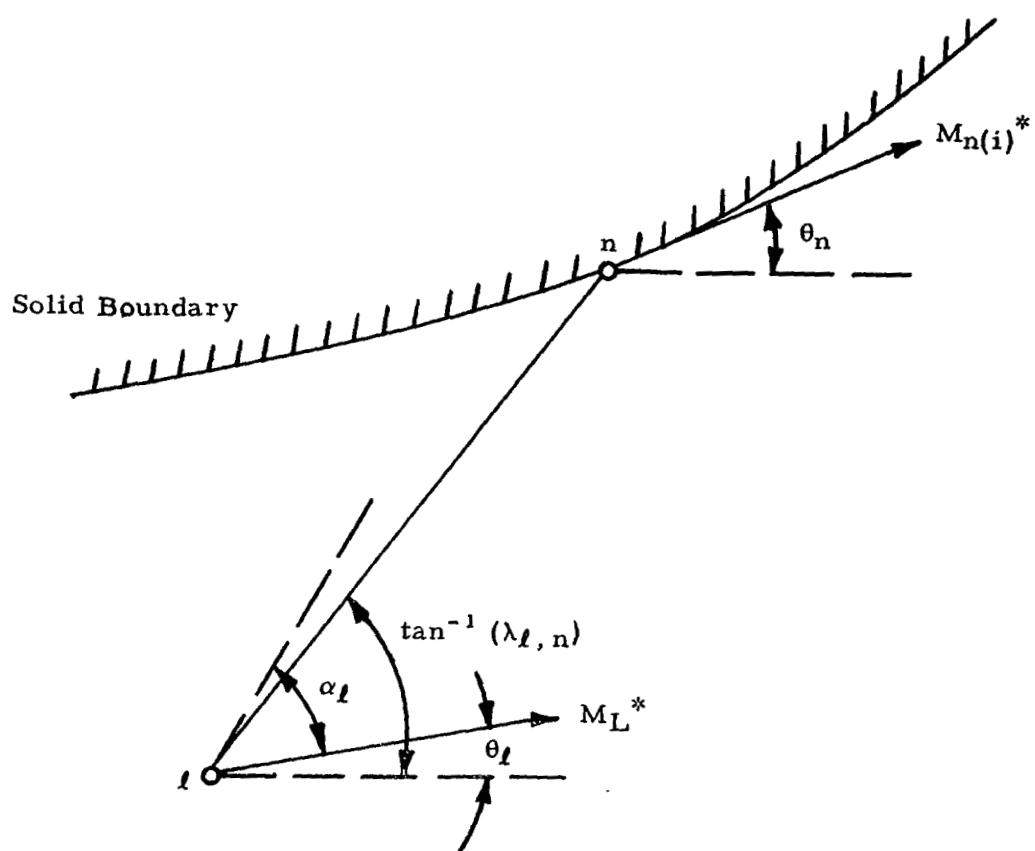


Figure A-3. Unit Process for Point on a Solid Boundary

$$3. \quad \beta_\ell = \frac{\sin \theta_\ell \sin \alpha_\ell}{y_\ell \sin (\theta_\ell + \alpha_\ell)}$$

$$4. \quad H_\ell = \frac{\cot \alpha_\ell}{M_\ell^*}$$

$$5. \quad \lambda_\ell = \tan (\theta_\ell + \alpha_\ell)$$

$$6. \quad \beta_{\ell,n} = \beta_\ell$$

$$7. \quad H_{\ell,n} = H_\ell$$

$$8. \quad \lambda_{\ell,n} = \lambda_\ell$$

9. Find x_n , y_n , and θ_n by solving the intersection of the left running characteristic with the contour.

$$10. \quad M_{n(i)}^* = \frac{\theta_n - \theta_\ell - \beta_{\ell,n} (y_\ell - y_n)}{H_{\ell,n}} + M_\ell^*$$

11. If either $|M_{n(i)}^* - M_n^*| \leq 10^{-7}$ or number of iterations exceed 50, return to the main program; otherwise, set $M_n^* = M_{n(i)}^*$ and go to step 12.

12. Obtain M_n from thermodynamic table using M_n^* as input.

$$13. \quad \alpha_n = \sin^{-1} \frac{1}{M_n}$$

$$14. \quad \lambda_n = \tan (\theta_n + \alpha_n)$$

$$15. \quad H_n = \frac{\cot \alpha_n}{M_n^*}$$

$$16. \quad \beta_n = \frac{\sin \theta_n \sin \alpha_n}{y_n \sin (\theta_n + \alpha_n)}$$

$$17. \quad H_{\ell, n} = \frac{H_\ell + H_n}{2}$$

$$18. \quad \lambda_{\ell, n} = \frac{\lambda_\ell + \lambda_n}{2}$$

$$19. \quad \beta_{\ell, n} = \frac{\beta_\ell + \beta_n}{2}$$

20. Go to step 9.

APPENDIX B

EQUATIONS FOR THE CALCULATION OF HALL'S CONSTANT PROPERTY CURVE

1. $x_1 = 0$

2. $x_1 = x_1 + \Delta x$

3. $y_1 = 1 + \frac{x_1^2}{2R} + \frac{\sigma x_1^4}{8R^3}$

4. Assume a value of γ

5. $a_1 = \frac{2\gamma + 9}{24}$

6. $a_2 = \frac{4\gamma + 15}{24}$

7. $a_3 = \frac{10\gamma + 57}{288}$

8. $a_4 = \frac{2\gamma - 3}{6}$

9. $a_5 = \frac{556\gamma^2 + 1899\gamma + 3231}{10368}$

10. $a_6 = \frac{388\gamma^2 + 1233\gamma + 1953}{2304}$

11. $a_7 = \frac{304\gamma^2 + 858\gamma + 1269}{1728}$

12. $a_8 = \frac{2708\gamma^2 + 7839\gamma + 14211}{82944}$

13. $a_9 = \frac{52\gamma^2 + 99\gamma + 375}{384}$

14. $a_{10} = \frac{52\gamma^2 + 99\gamma + 303}{192}$

$$15. \quad a_{11} = \frac{200 \gamma^2 + 72 \gamma + 639}{1152}$$

$$16. \quad a_{12} = \frac{5 \gamma - 5}{8}$$

$$17. \quad a_{13} = \frac{13 \gamma - 27}{48}$$

$$18. \quad a_{14} = \frac{4 \gamma^2 - 57 \gamma + 27}{144}$$

$$19. \quad b_1 = \frac{8 \gamma + 15}{72}$$

$$20. \quad b_2 = \frac{20 \gamma + 45}{96}$$

$$21. \quad b_3 = \frac{28 \gamma + 75}{288}$$

$$22. \quad b_4 = \frac{4 \gamma + 9}{12}$$

$$23. \quad b_5 = \frac{6836 \gamma^2 + 16695 \gamma + 14211}{82944}$$

$$24. \quad b_6 = \frac{3380 \gamma^2 + 8703 \gamma + 7875}{13824}$$

$$25. \quad b_7 = \frac{3748 \gamma^2 + 8859 \gamma + 8964}{13824}$$

$$26. \quad b_8 = \frac{9044 \gamma^2 + 17631 \gamma + 20745}{82944}$$

$$27. \quad b_9 = \frac{556 \gamma^2 + 1113 \gamma + 981}{1728}$$

$$28. \quad b_{10} = \frac{388 \gamma^2 + 801 \gamma + 693}{576}$$

$$29. \quad b_{11} = \frac{304 \gamma^2 + 645 \gamma + 549}{864}$$

30. $b_{12} = \frac{52 \gamma^2 + 3 \gamma - 33}{192}$

31. $b_{13} = \frac{52 \gamma^2 + 27 \gamma - 9}{192}$

32. $b_{14} = \frac{\gamma + 1}{4}$

33. $z = x_1 \sqrt{\frac{2R}{\gamma + 1}}$

34. $q_1 = \frac{1}{2} y_1^2 - \frac{1}{4} + z$

35. $q_2 = a_1 y_1^4 - a_2 y_1^2 + a_3 + z \left(y_1^2 - \frac{5}{8} \right) - a_4 z^2$

36. $q_3 = a_5 y_1^6 - a_6 y_1^4 + a_7 y_1^2 - a_8 + z (a_9 y_1^4 - a_{10} y_1^2 + a_{11})$
 $+ z^2 (a_{13} - a_{12} y_1^2) + a_{14} z^3$

37. $\bar{q} = 1 + \frac{q_1}{R} + \frac{q_2}{R^2} + \frac{q_3}{R^3}$

38. Obtain $\bar{\gamma}$ from thermodynamic table (by entering \bar{q} , i.e., M*)

39. If $|\gamma - \bar{\gamma}| \leq 10^{-5}$, go to step 40. Otherwise, set $\gamma = (\gamma + \bar{\gamma})/2$ and
 go to step 5

40. Obtain M from thermodynamic table (by entering \bar{q})

41. $\alpha = \sin^{-1} \frac{1}{M}$

42. $\theta_s = \tan^{-1} \left(\frac{x_1}{R} + \frac{\sigma x_1^3}{2 R^3} \right)$

43. $Q = (\bar{q} - 1) \cdot R$

44. $g_0 = Q - 0.5 y^2 + 0.25$

45. $g_1 = a_2 y^2 - a_1 y^4 - a_3 + g_0 \left[g_0 a_4 - \left(y^2 - \frac{5}{8} \right) \right]$

46. $g_2 = -a_5 y^6 + a_6 y^4 - a_7 y^2 + a_8 - g_0 [(a_9 y^4 - a_{10} y^2 + a_{11})$
 $+ g_0 (-a_{12} y^2 + a_{13}) + g_0^2 a_{14}]$

47. $\frac{dg_0}{dy} = -y$

48. $\frac{dg_1}{dy} = 2 a_2 y - 4 a_1 y^3 + 2 a_4 g_0 \frac{dg_0}{dy} - 2 g_0 y - \frac{dg_0}{dy} \cdot y^2 + \frac{5}{8} \cdot \frac{dg_0}{dy}$

49. $\frac{dg_2}{dy} = -6 a_5 y^5 + 4 a_6 y^3 - 2 a_7 y - a_9 y^4 \frac{dg_0}{dy} - 4 a_9 g_0 y^3$
 $+ a_{10} \frac{dg_0}{dy} \cdot y^2 + 2 a_{10} g_0 \cdot y - a_{11} \frac{dg_0}{dy} + 2 a_{12} g_0 \frac{dg_0}{dy} \cdot y^2$
 $+ 2 a_{12} g_0^2 \cdot y - 2 a_{13} g_0 \cdot \frac{dg_0}{dy} - 3 a_{14} g_0^2 \frac{dg_0}{dy}$

50. $\frac{dz}{dy} = \frac{dg_0}{dy} + \frac{1}{R} \frac{dg_1}{dy} + \frac{1}{R^2} \cdot \frac{dg_2}{dy}$

51. $\frac{dy}{dx} = \frac{1}{\left(\sqrt{(y+1)/2R} \cdot \frac{dz}{dy} \right)}$

52. $\Delta = \tan^{-1} \left(\left| \frac{dy}{dx} \right| \right)$

53. If $0.03 < \Delta - |\theta_s| - \alpha \leq 0.05$, go to step 54. Otherwise, go to step 2.

54. Find the y_i 's (equally spaced between 0 and y_1)

55. Find g_0, g_1, g_2 from Equations 44, 45, 46, respectively.

56. $z = Q - 0.5 y_i^2 + 0.25 + \frac{g_1}{R} + \frac{g_2}{R^2}$

$$57. \quad x_i = z \sqrt{(\gamma + 1)/2R}$$

$$58. \quad \theta_1 = 0.25 y_i^3 - 0.25 y_i + y_i z$$

$$59. \quad \theta_2 = b_1 y_i^5 - b_2 y_i^3 + b_3 y_i + b_4 z (y_i^3 - y_i)$$

$$60. \quad \theta_3 = b_5 y_i^7 - b_6 y_i^5 + b_7 y_i^3 - b_8 y_i + z (b_9 y_i^5 - b_{10} y_i^3 + b_{11} y_i) \\ + z^2 (b_{12} y_i^3 - b_{13} y_i) - b_{14} y_i z^3.$$

$$61. \quad \theta_i = \sqrt{\frac{\gamma + 1}{2R}} \cdot \left(\frac{\theta_1}{R} + \frac{\theta_2}{R^2} + \frac{\theta_3}{R^3} \right)$$

APPENDIX C

EQUATIONS FOR THE CALCULATION OF NOZZLE PERFORMANCE

Along the Starting Line

$$1. \quad \theta_V = (\theta_1 + \theta_2)/2$$

$$2. \quad \theta_N = \tan^{-1} \left(\frac{x_1 - x_2}{y_2 - y_1} \right)$$

$$3. \quad \theta_T = \theta_N - \theta_V$$

4. Find average pressure, temperature, specific heats ratio,
molecular weight from the thermodynamic table. (P_s, T_s, G_s, W_s)

$$5. \quad C_s = \sqrt{g_c \cdot G_s \cdot R \cdot T_s / W_s}$$

$$6. \quad V_s = C_s \cdot (M_1 + M_2) / 2$$

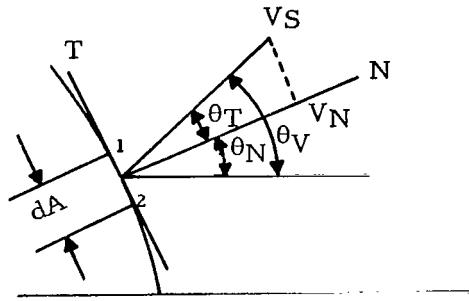
$$7. \quad \rho_s = P_s W_s / (\bar{R} T_s)$$

$$8. \quad dA = |\pi(y_2^2 - y_1^2) / \cos \theta_N|$$

$$9. \quad V_N = V_s \cos \theta_T$$

$$10. \quad \Delta \dot{m} = dA \rho_s V_N$$

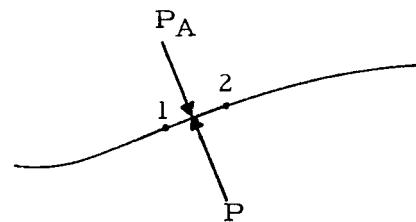
$$11. \quad \Delta \Gamma_s = dA \cdot P_s \cdot \cos \theta_N + \Delta \dot{m} \cdot V \quad \text{at } \theta_V = P_a \cdot dA \cdot \cos \theta_N$$



Along the Nozzle Contour

$$12. \quad P = A_{N+1} y^N + A_n y^{N-1} + \dots + A_1$$

$$13. \quad \Delta \Gamma_c = 2\pi \int_1^2 P \cdot y dy - P_a \cdot \pi (y_2^2 - y_1^2)$$



Overall

14. $\Gamma = \Gamma_s + \Gamma_c$

15. Sp. Imp. = Γ / \dot{m}

16. CF = $\Gamma / (P_c \cdot \pi \cdot R_t^2)$

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